BASS LAKE
DIAGNOSTIC STUDY

Starke County, Indiana

July 9, 2002

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BASS LAKE DIAGNOSTIC STUDY
EXECUTIVE SUMMARY

Bass Lake is a 1,400 acre (570 ha) natural lake located approximately 5 miles southeast of Knox, Indiana in the southeast corner of Starke County. The lake's small watershed encompasses approximately 3060 acres (1240 ha). Bass Lake itself covers almost half of the watershed (47%). Much of the remaining portion of the watershed is forested (21%) or utilized for residential (15%) or agricultural (9.5%) purposes. An analysis of hydric soils in the watershed suggests that approximately 23% of the original wetland acreage exists today. Development of the shoreline for residential use is the primary cause of this loss. Fifty seven acres (23 ha) of land in the watershed is mapped in a potentially highly erodible soil unit.

Bass Lake is best classified as a eutrophic lake. The lake supports an extremely small rooted plant community that covers less than one percent of the lake's surface area. Channel catfish dominate the lake's fish community. White crappie, white bass, gizzard shad, quillback, and walleye are also major species in the community. In general, Bass Lake possesses poorer water quality than most other Indiana lakes. Bass Lake exhibits high total phosphorus and total organic nitrogen concentrations. Total phosphorus concentrations appear to be increasing with time. The lake's water clarity is poor with current and historical Secchi disk transparency measurements typically ranging from 1 to 4 feet. In August of 2001, the lake experienced blooms of nuisance algae including *Microcystis*, *Anabaena*, and *Cylindrospermopsis*. Phosphorus modeling indicates that 76% of the phosphorus in the lake originates from internal sources.

Bass Lake is immensely popular as a recreational resource. A resident survey revealed that large percentages of the lake residents swim, boat, use personal watercraft, and fish on the lake. The most frequently used areas are the deep portions of the lake and the lake's shoreline. In general, residents do not use the lake's southwest basin. Concerns over lake water level and water clarity top residents list of biggest problems on the lake.

Water balance modeling revealed that 47% of lake's inflow comes from groundwater seepage and 30% of the lake's inflow is from precipitation. The Bass Lake Conservancy District's pumping operation makes up much of the remaining inflow. Very little of the lake's inflow comes from surface water drainage. Based on an evaluation of the geology in the area surrounding the lake, the clay layer separating the upper groundwater aquifer from the lower groundwater aquifer appears to be discontinuous. The connectivity of the two aquifers may have implications for any long-term operations.

To address residents' concerns and improve Bass Lake's water quality, the following action items are recommended: 1. Implement the groundwater monitoring system to evaluate the extent of connection between the upper and lower groundwater aquifers near Bass Lake; 2. Develop a recreational use management plan; 3. Conduct a feasibility study to determine the success of an alum treatment; 4. Consider adding an alum dosing structure to the pump outfall; 5. Develop aquatic macrophyte (rooted plant) management plan; and 6. Implement homeowner action items.

ACKNOWLEDGMENTS

This Diagnostic Study was performed with funding from the Indiana Department of Natural Resources - Division of Soil Conservation and the Bass Lake Property Owners Association, Inc. (BLPOA). The team of J. F. New and Associates, Inc., the Indiana University Geological Department, and the Indiana University Center for Geospatial Design documented the historical information, completed lake sampling, analyzed resident survey data, and created a water balance and phosphorus budget model for the lake. Special thanks are due to Bass Lake property owners Gene Blastic, Bill Sonnemaker Ken Smith and George Lauder for their initiative and assistance in getting this study completed. Jill Hoffman, Carol Newhouse, Bill Jones, and numerous others provided thoughtful comments and feedback during data analysis and report writing. Authors of this report include Greg Olyphant, Kevin Spindler, Alexey Zlotin and James Boswell at Indiana University, and Marianne Giolitto, Steve Zimmerman, Sara Peel, and Cornelia Sawatzky at J. F. New and Associates, Inc. Brian Majka of J.F. New and Associates, Inc. provided GIS maps of the study area.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDICES

A. Bass Lake Property Owners Association Resident Survey
B. Explanation of Supporting Visualization Files for Bass Lake Geology
C. Endangered, Threatened, and Rare Species List, Bass Lake Watershed
D. Endangered, Threatened, and Rare Species List, Starke County
E. Explanation of Supporting Visualization Files for Lake Level Changes
F. BonHomme Eutrophication Index Calculations for Bass Lake, 1975, 1977 and 1988
G. PhycoTech's Plankton Enumeration Protocol
H. Laboratory Results from the August 2001 Water Quality Sampling
I. Informational News Release on *Cylindrospermopsis*
J. Bass Lake Fish Species Lists
K. Bass Lake Macrophyte Species List

BASS LAKE DIAGNOSTIC STUDY
STARKE COUNTY, INDIANA

INTRODUCTION

Bass Lake lies in the middle portion of the Kankakee River watershed immediately southeast of Knox, Indiana (Figure 1). The lake occupies the eastern portion of the USGS 14 digit watershed numbered 07120001-070-010. Specifically, Bass Lake is located in Sections 7 and 18, Township 32 North, Range 1 West and Sections 12, 13, 14, 23, and 24, Township 32 North, Range 2 West. The lake's small watershed extends out to the north and east of the lake. When lake water levels are high enough to allow for discharge from the lake, water exits the lake in the southwest corner. A series of ditches transport the lake water in a northwesterly direction ultimately reaching the Kankakee River, at the Kankakee State Fish and Wildlife Area.

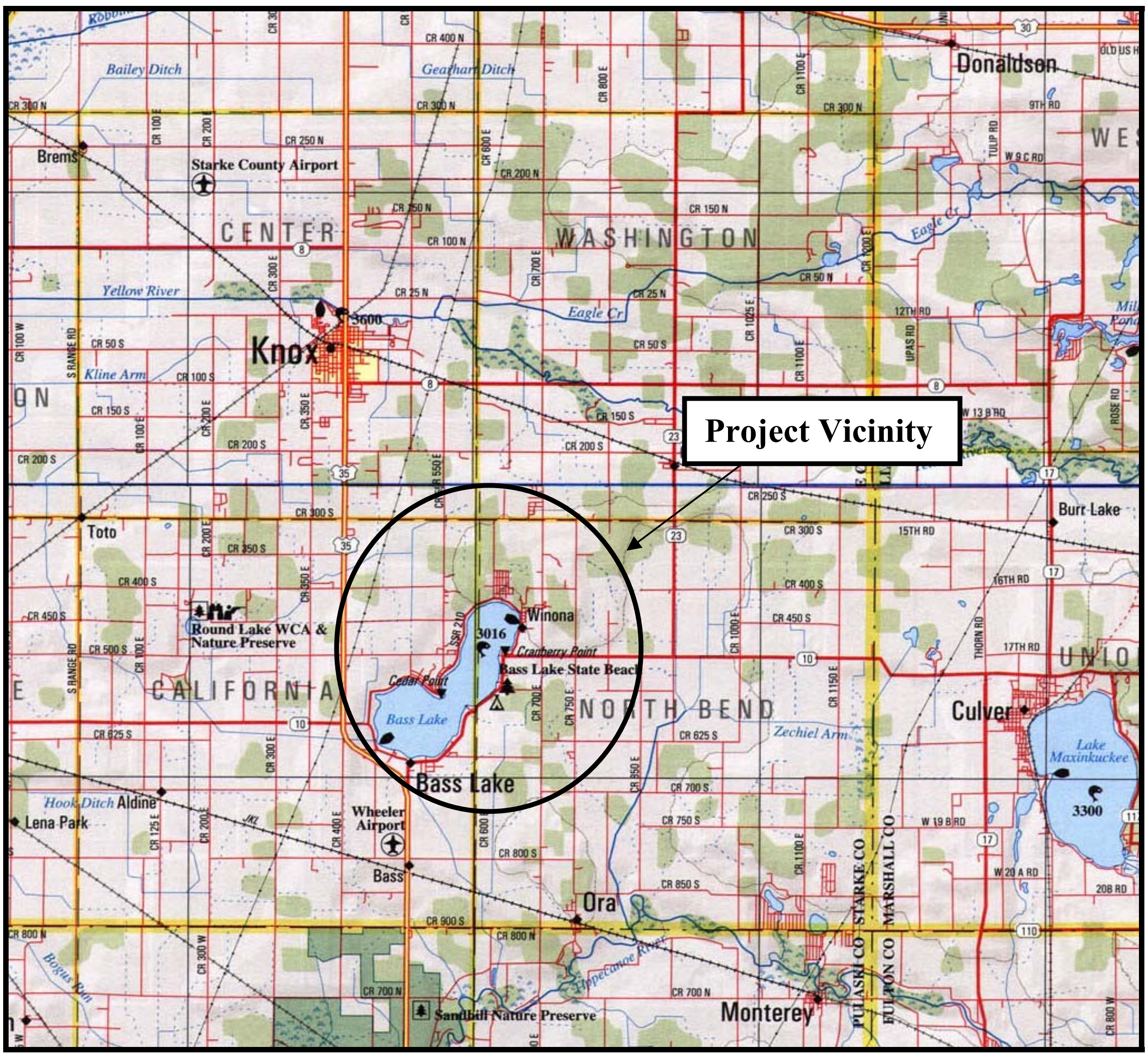

Figure 1. Location map for the Bass Lake Diagnostic Study. Source of Base Map: DeLorme, 1998.

Bass Lake and its watershed formed during the glacial activity of the latter Pleistocene era. The era's glacial advance and recent laid down clay-rich till and deposited sandy outwash materials that constitute the area's geologic setting today. Bass Lake itself may have originated as an ice block trapped in this outwash and till material. As temperatures increased with climatic change following the ice age, the ice block melted forming the lake that exists today.

Based on this geology, Bass Lake and its watershed lie in the Kankakee Sand Section of the Grand Prairie Natural Region (Homoya et al., 1985). The Grand Prairie Natural Community covers much of the northwestern portion of the state, bound roughly by the Valparaiso Moraine to the north and the Wabash River to the south. The lack of forested communities characterizes this natural area. Typical natural communities found in the Kankakee Sand Section of the Grand Prairie Natural Region include sand prairies and savannas in the upland areas and wet prairies, marshes, swamps, wet sand flats and wet sand/muck flats in the lower areas of the landscape. Few of these natural communities exist in the region today; Homoya et al. (1985) note that "this region is the most altered of all natural regions in the state."

These changes occurred in and around the Bass Lake watershed as well. Corn and soybean fields have replaced prairies populated with big and little bluestem, Indian grass, compass plant, coneflowers, and other prairie species. Agricultural ditches facilitate drainage in low areas where many of the wet communities listed above may have existed. Homes and manicured lawns border the edge of Bass Lake. This land was previously occupied by marshes and sand and sand/muck flats that were intermittently exposed as the lake level fluctuated with changes in climatic conditions.

Bass Lake itself has experienced changes over the past century. Early documentation describes a beautiful, well vegetated lake providing an excellent fishery for vacationers (Blatchley, 1900). While published literature of the last several decades indicates the lake's fishery is still satisfactory, the lake's clarity is less than desirable. Water clarity measurements show Bass Lake is less clear than most other Indiana lakes. Additionally, lake residents have noted a decline in lake water level in recent years.

In an attempt to understand the reasons for the observed changes in their lake and to investigate possible solutions to the problems facing their lake, the Bass Lake Property Owners Association (BLPOA) applied for and received funding from the Indiana Department of Natural Resources (IDNR) Lake and River Enhancement Program (LARE) for a lake and watershed diagnostic study. The purpose of the study is to describe the conditions and trends in Bass Lake and its watershed, identify potential problems and make prioritized recommendations addressing these problems. The study included a review of historical studies, interviews with lake residents and state/local regulatory agencies, the collection of lake water quality samples, an inventory of macrophytes and plankton, and field investigations identifying land use patterns. To address the lake water level issues, the study also included an evaluation of the geology and hydrology of the land immediately surrounding the lake. The BLPOA assisted with the study by distributing and entering data on completed resident surveys and by conducting boat counts. This report documents the results of the study.

RESIDENT SURVEY

During the spring of 2001, J.F. New and Associates the Bass Lake Property Owners Association, Inc. (BLPOA) conducted a resident survey. The primary purpose of the survey was to assist in developing a complete picture of the lake conditions. The survey contained questions regarding lake resident's property characteristics and uses, lake usage, and resident views on specific issues. For reference, a blank survey is provided in Appendix A.

Methods

The BLPOA mailed a copy of the survey with an information letter in their annual spring mailing to all property association members. Bass Lake Conservancy District members who are not part of the BLPOA also received the surveys. In total, approximately 1050 lake residents received surveys in early April 2001. The BLPOA encouraged residents to return completed surveys by including a pre-addressed envelope in the mailing. Residents could also drop off surveys at the BLPOA building. The BLPOA accepted surveys through July 1, 2001. The association received 488 completed surveys and 44 partially completed surveys. The survey results include only the 488 completed surveys. Lake residents and members of a community workforce development organization entered data for the completed surveys in an Excel spreadsheet.

Lake residents conducted three boat counts in conjunction with the resident survey. In the first boat count, a resident team counted the number of boats with motors moored around Bass Lake. The two other counts tabulated the number of boats on the lake at any given time. The first of these two counts occurred on July 1, 2001. The second took place on July 15, 2001. In each count, the resident team counted the number of boats on the lake every two hours starting at 8 AM and concluding at 8 PM. Under this methodology, boaters that remain on the lake for more than 2 hours may be counted two (or more) times. For example, an angler who fished from 9 to 1 on would be included in the 10 AM count and again in the 12 PM count. Alternatively, those who boated for less than 2 hours (i.e. someone who was on the lake from 12:30 to 1:30) may not be included in the count. To estimate lake usage by non-residents, the resident team also counted the number of boats launched from the public boat launch on July 1, 2001.

Resident Survey Results

Results General Characteristics

Just over half of the survey respondents lived on the lake at the time of survey. Forty-five percent of the respondents lived around but not on the lake. Approximately 35% of survey respondents were relatively newer residents around the lake having lived there for less than ten years (Figure 2). Nearly six percent of the respondents were longtime lake residents having lived in the area for more than 50 years. One noted s/he had lived on Bass Lake for 100 years!

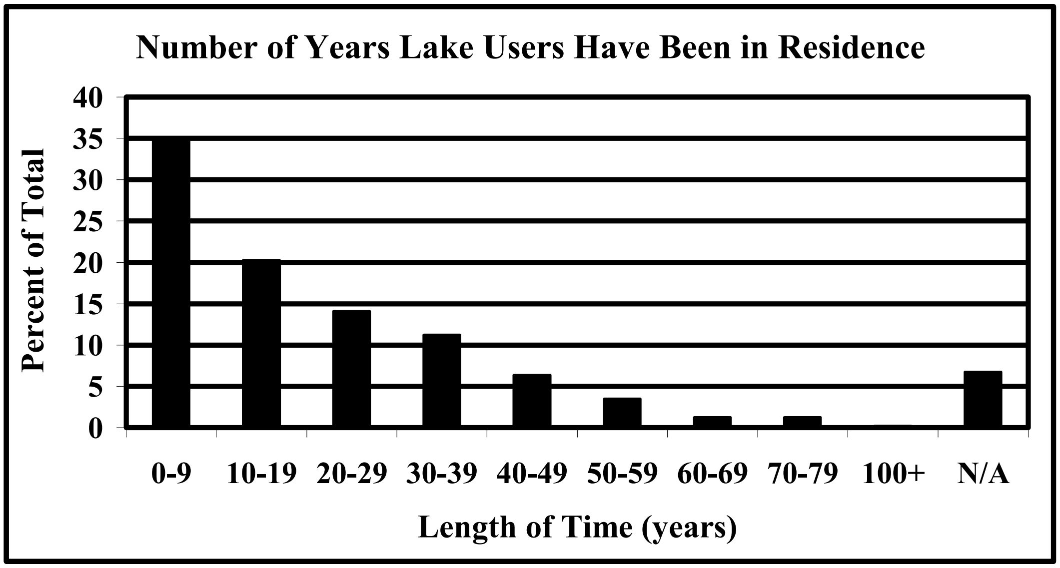

Figure 2. Length of residence of survey respondents around Bass Lake expressed as a percent of the total surveyed. An answer of N/A means that the resident answering the question either could not determine or felt that the question was inapplicable.

As is typical around many northern Indiana lakes, respondents occupied their homes for differing periods of time (Figure 3). Twenty-four percent of the respondents occupied their lake homes year round. Many utilized their homes on a seasonal basis, with 18% of the respondents noting that they lived at the lake only in the summer and another 21% noting that they lived at the lake only on summer weekends. Another 16% of the respondents lived at the lake on weekends throughout the year, while 11% occupied their lake homes on weekends except during the winter months.

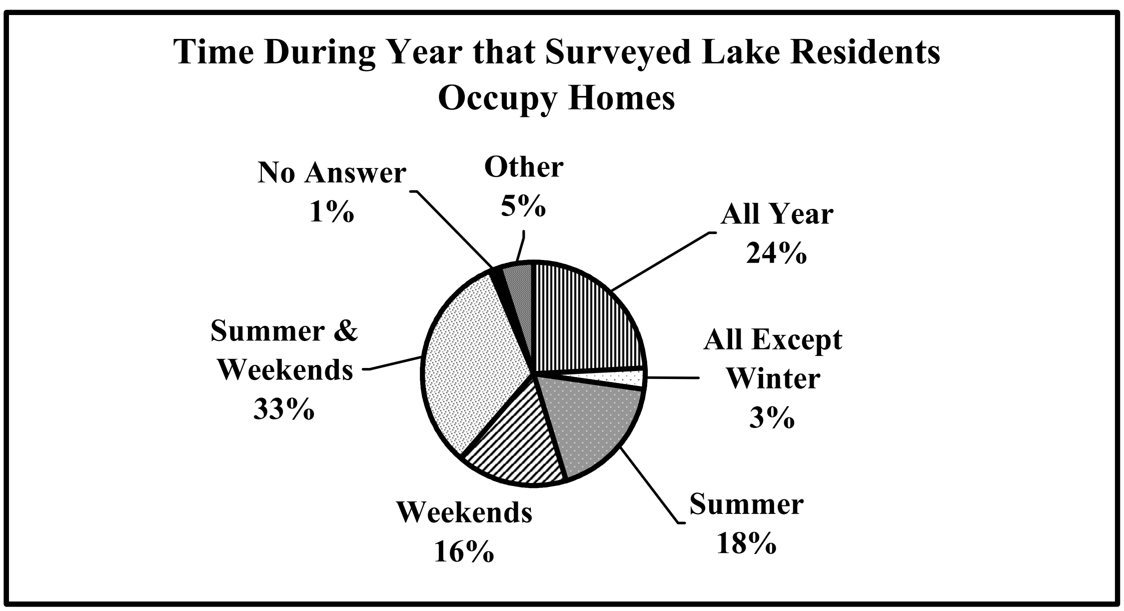

Figure 3. Time during year that surveyed residents occupy homes expressed as a total of the residents surveyed.

Residents were asked about the age of their homes. This information provides clues to when modern development around the lake began. It also indicates whether development is continuing around the lake or if property owners are replacing older cottages with newer homes to allow for full time residence. As shown in Figure 4, homes around Bass Lake range in age from very new (0-1 year) to very old (100+ years). Although there is a very even distribution in home age, most homes were 40 to 60 years old at the time of the survey. Nearly 9% of the homes were 80 years old or older and approximately 5% of the respondents stated that their homes were more than 100 years old.

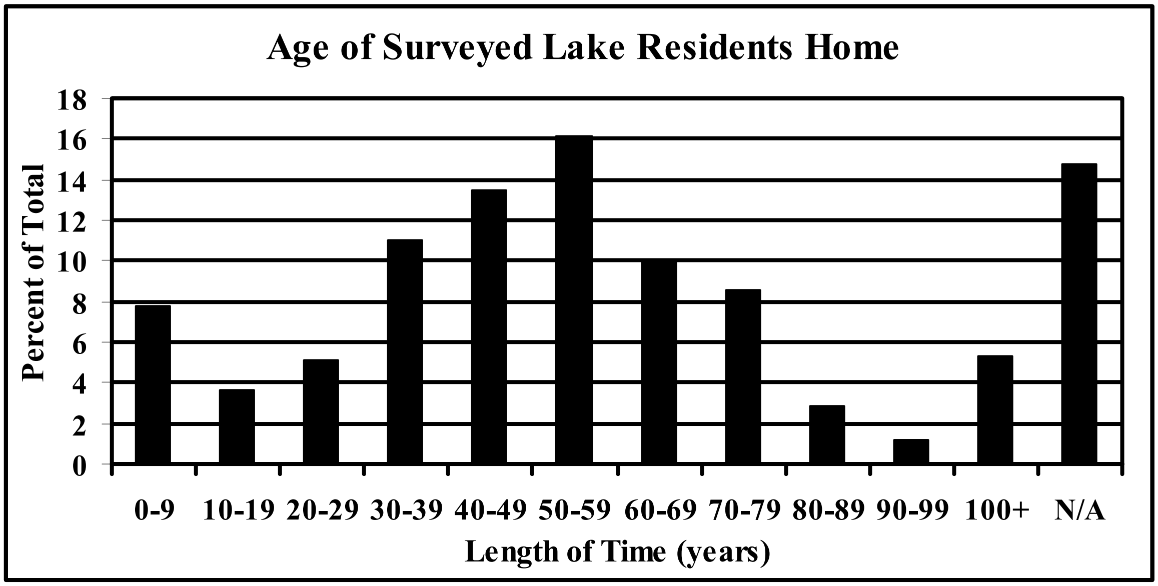

Figure 4. Ages of homes owned by survey respondents around Bass Lake expressed as a percent of the total surveyed.

The survey included questions regarding how residents care for their property. Nearly 42% of the survey respondents stated that they fertilize their lawns. Of those who fertilize their lawns, most (73%) apply fertilizer once or twice a year. Fortunately, a large majority of those who fertilize their lawns always or at least sometimes use a phosphorus free fertilizer (43% and 30%, respectively). Only 17% of the survey respondents stated that they apply pesticide to their lawns. As with the fertilizer use, those who apply pesticide typically apply it once or twice a year. Only two respondents noted that they applied herbicides to the lake vegetation along their shoreline.

Seawall usage is slightly less common on Bass Lake compared to other lakes in the region. Only 37% of the respondents noted the presence of a seawall along their shoreline. Most of the seawalls (58%) are concrete seawalls. Approximately a third of the seawalls consist of riprap or other stone material. Wood and sheet metal seawalls were also noted around Bass Lake.

Lake Usage

When asked how they utilized the lake, respondents reported swimming and boating as their favorite activities on Bass Lake (Figure 5). Eighty-two percent of the respondents noted that they swim in the lake. Seventy-eight percent of the respondents boat on the lake. Fishing ranked third in popularity with approximately 46% of the respondents noting that they participate in this lake activity. A surprisingly high percentage of respondents (42%) operate personal watercraft on the lake. In an open space on the survey, respondents listed a variety of other activities that they enjoy on or around the lake including picnicking, sun bathing, and knee boarding.

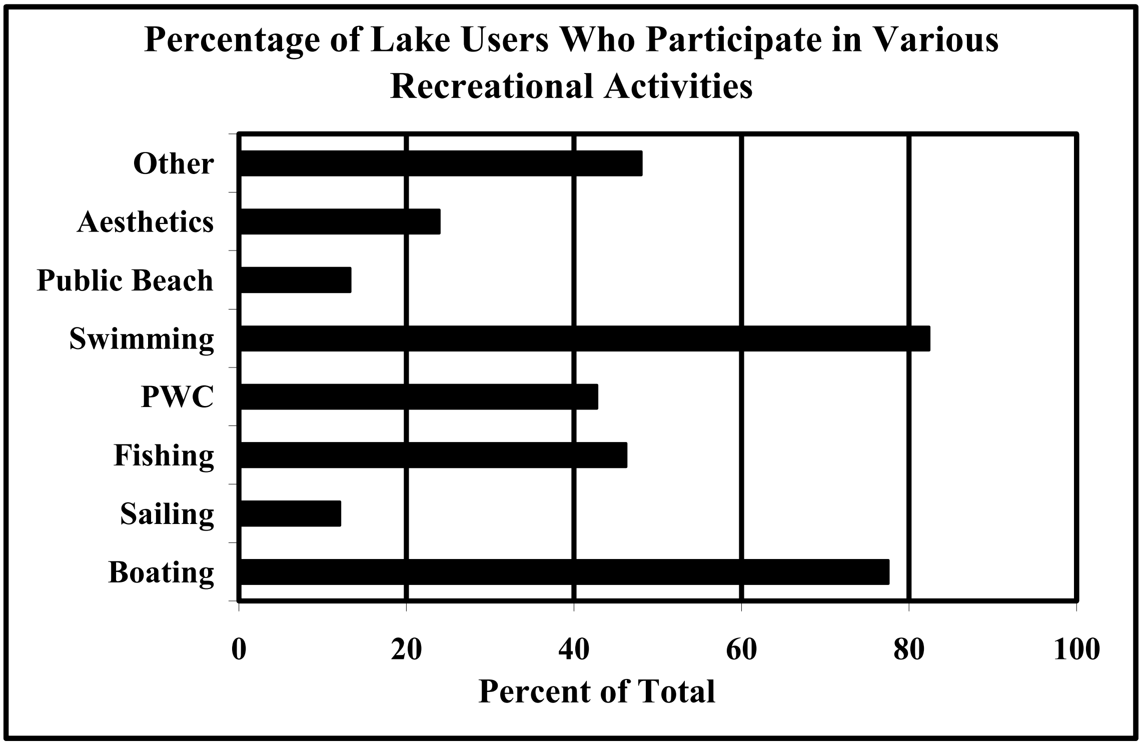

Figure 5. Percentages of surveyed lake users who participate in various recreational activities on Bass Lake. PWC refers to the use of personal watercraft such as jet skis, etc.

The survey also contained questions asking residents to specify where they participated in their favorite activities on the lake. Survey respondents answered these questions by shading a map of the lake. Figure 6 shows the top three answers of residents when asked which area(s) of the lake they utilize the most. The deep areas rated as the most frequently used areas on the lake with slightly less than 20% of respondents using these areas. Another 16% of respondents were more specific reporting that they spent most of their time in the deep areas of the northern basin. Nearly equal numbers of respondents answered that they utilized the whole lake or the area in front of their homes most frequently. More than a quarter of the respondents did not answer this question.

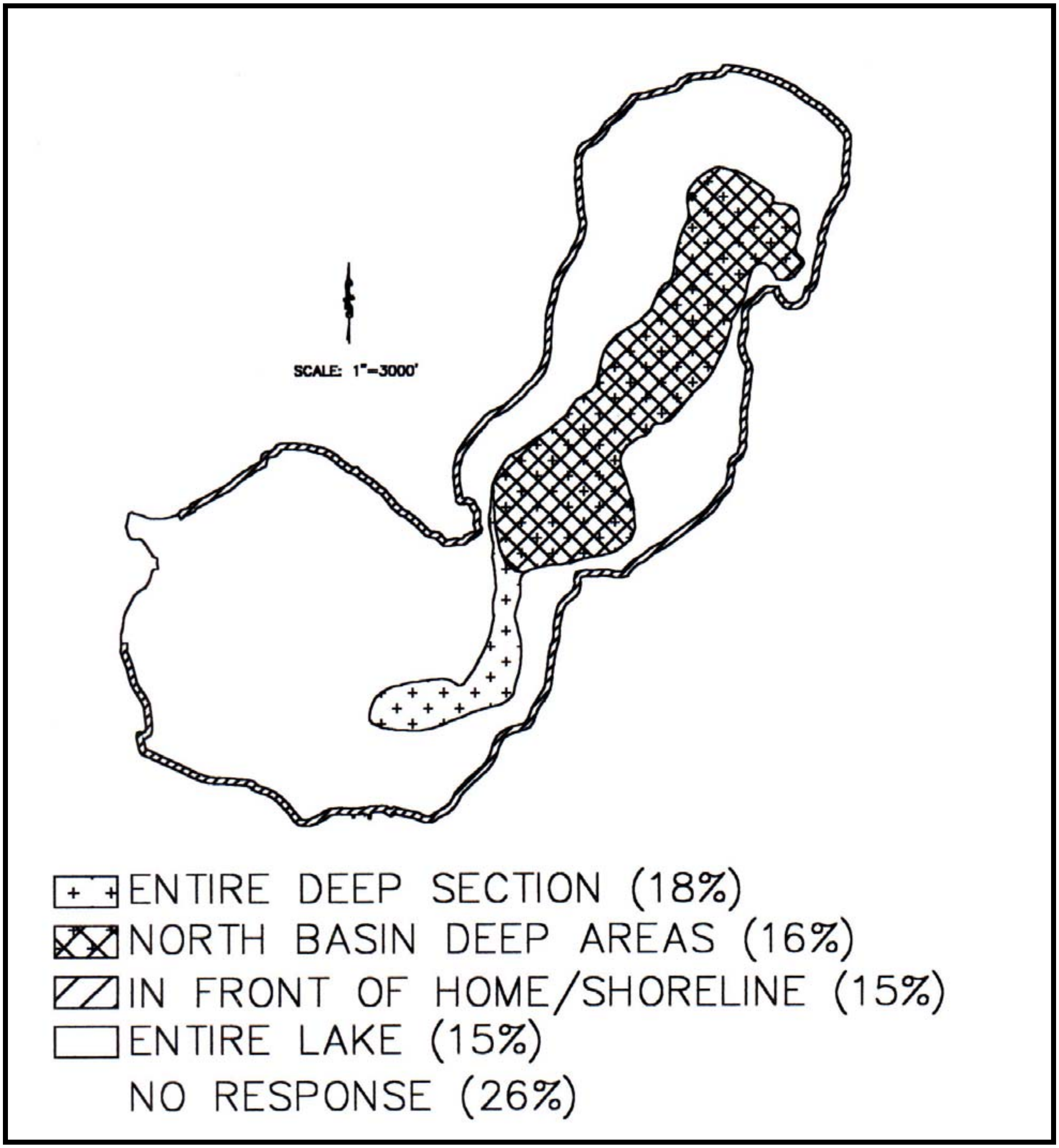

Figure 6. Areas identified as those most used by survey respondents. Source of Base Map: U.S.G.S. 7.5 Minute Topographical Map.

Figure 7 illustrates the responses to the question inquiring which area of the lake residents utilized the least. Twenty two percent of the respondents reported that they did not use the lake's southwest basin. An additional 18% of respondents were more specific, noting that they did not use the northern half of the southwest basin. Nearly 35% of the respondents did not answer the question.

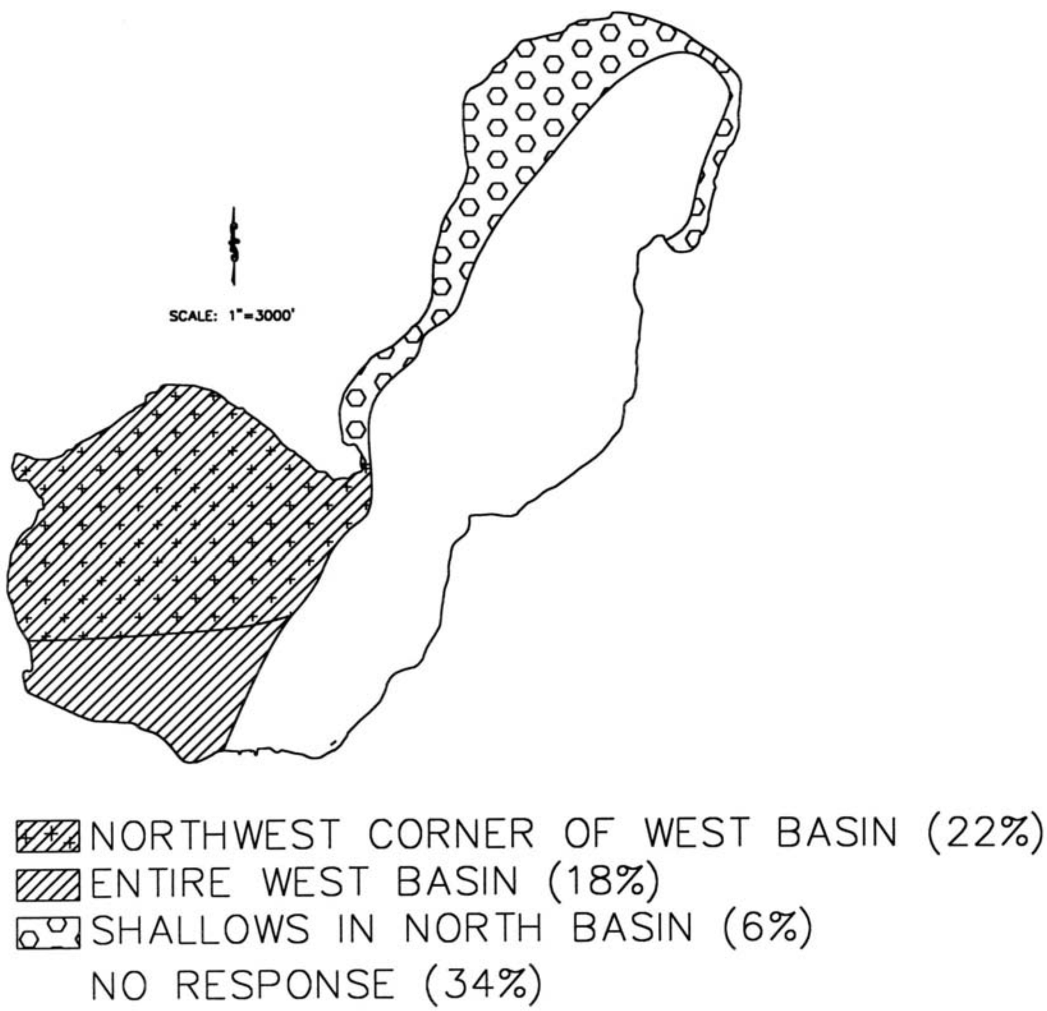

Figure 7. Areas identified as least used by survey respondents. Source of Base Map: U.S.G.S. 7.5 Minute Topographical Map.

The survey contained a related use question inquiring where residents fished on the lake. Twelve percent of the respondents reported that they fished in front of their homes (Figure 8). Another 10% of respondents indicated that they fished across the entire lake. Seven percent preferred the lake's deep holes. Most survey recipients (59%) did not answer this question. (The surveys noted that only those who fished on the lake should answer the question. This accounts for the relative lack of responses to this question compared to other survey questions.)

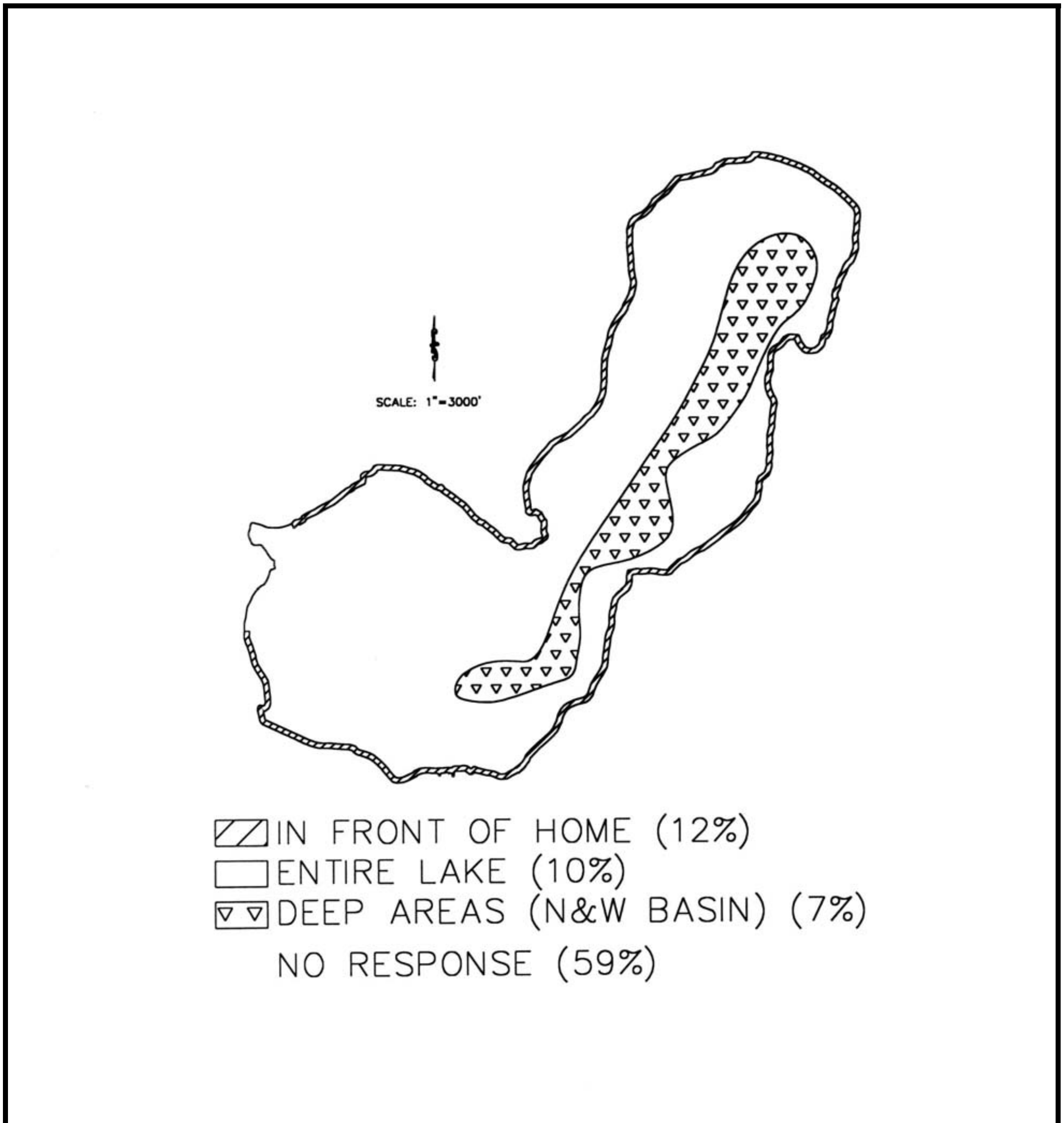

Figure 8. Areas identified as most used by survey respondents for fishing. Source of Base Map: U.S.G.S. 7.5 Minute Topographical Map.

Lake residents conducted several boat counts in conjunction with the resident survey. One counted the number of boats with motors moored around Bass Lake. The result of this count was 915 motorized boats. Two other counts tabulated the number of boats on the lake at any given time. The first of these counts occurred on July 1, 2001. The weather on July 1 was cold and windy. Every two hours, lake residents counted the number of boats on the lake. (Refer to the methods part of this section for a discussion of how boats were counted.) Lake residents observed fewer than 150 boats total on the lake. Of this 150, 35 boats were launched from the public boat launch suggesting approximately 25% of the boaters did not live at Bass Lake.

Lake residents conducted a second boat count on July 15, 2001. The weather was more typical of mid-summer compared to the weather experienced two weeks earlier. Table 1 summarizes this second count. The total count on July 15 was 735. Peak boating activity occurred from 12 PM to 4 PM, with nearly 200 boats on the lake at 2 PM. Relatively few boaters utilized the lake in the early morning (8 AM) and late evening (8 PM).

Table 1. Boat count on Bass Lake at 2-hour increments, July 15, 2001.

Time	8 AM	10 AM	12 PM	2 PM	4 PM	6 PM	8 PM
Number of Boats	27	86	129	192	158	91	52

Fishing

The survey contained several questions to identify angler characteristics. As noted above, approximately 46% of the survey respondents stated that they fish on the lake. When those who noted they fished on the lake were asked when, during the week, they were most likely to fish, most (42%) responded that they fished on the weekends. Thirty four percent responded that they fished on weekends and weekdays. Fewer than ten percent stated that they fish on weekdays only. Respondents were most likely to fish in the summer months (Figure 9). Approximately 45% of the respondents stated that they fished in the spring and 42% noted that they fished in the fall. Few (5%) of the respondents fished during the winter months.

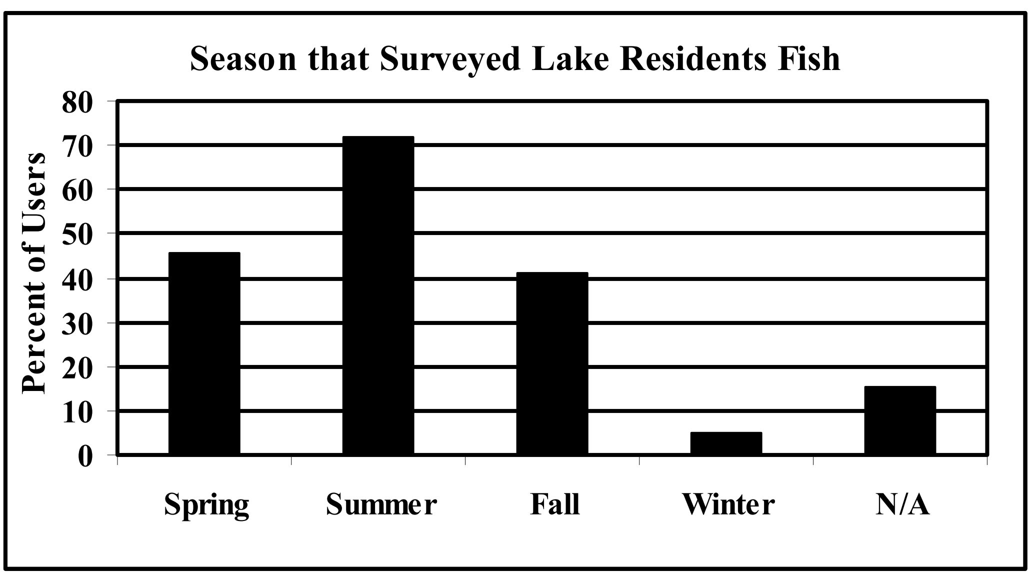

Figure 9. Season in which responding lake residents utilize the Bass Lake fishery expressed as a percentage of total surveyed.

Fishing from boats is more popular than fishing from the shore. Forty-seven percent of the lake's resident anglers stated that they fished from boats, while 32% stated that they fished from both boats and the shore. Only approximately 20% of the respondents stated that they fished only from the shore. (Shore fishing included wading.)

Bass Lake anglers fish for a variety of species. The survey contained an open-ended question regarding species preference. "Any species" was the most popular answer to this question (Figure 10). Walleye and catfish were the most popular species among the anglers responding to the survey. Twenty-three percent of the respondents stated they fished for walleye, while 18 % noted they fished for catfish. Fifteen percent of the respondents fished for bass; fourteen percent fished for crappie. One respondent noted that s/he fished for shark in Bass Lake.

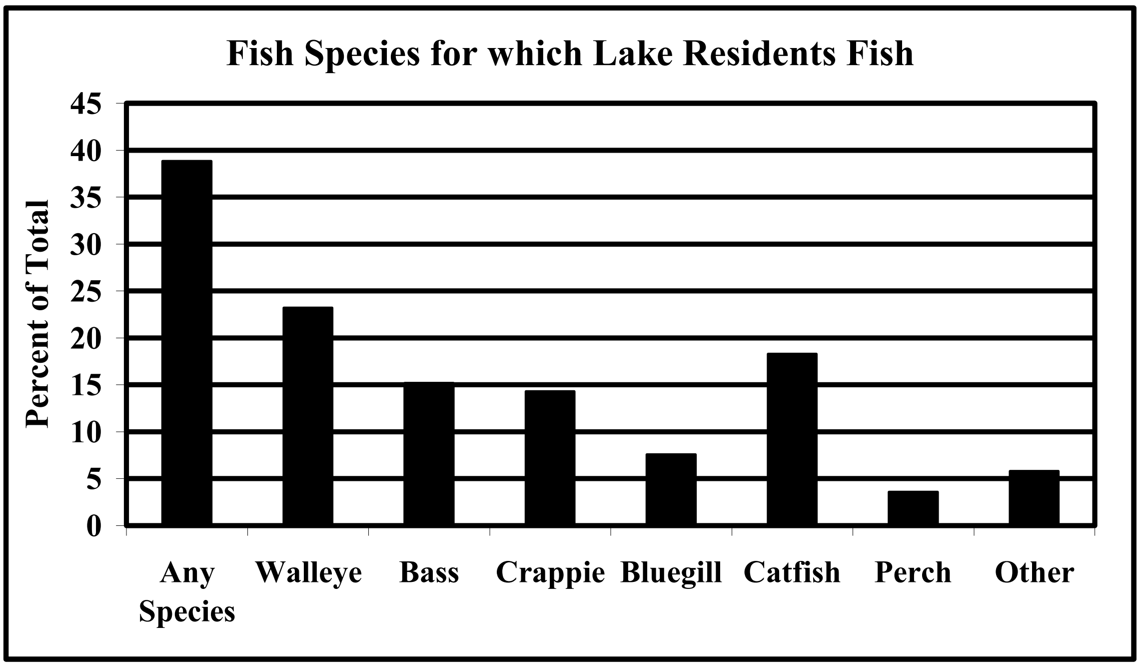

Figure 10. Types of fish species most commonly fished for by Bass Lake residents expressed as a percent of total.

Residents' Views and Perceptions

The survey contained a variety of questions designed to elicit residents' view and perceptions about the lake. One such question listed several potential problems and asked respondents which was the biggest problem at Bass Lake. Respondents could provide a write-in answer if the problems listed on the survey did not include what they saw as the lake's biggest problem. If the respondent felt the lake had more than one biggest problem, the survey notes that the respondent should rank the problems. Respondents overwhelming reported lake water level was the biggest problem at Bass Lake (Figure 11). Water clarity stood out at the second biggest problem. Respondents weighted the problems of boat traffic, boat speed, personal watercraft use, and erosion almost equally, and few respondents ranked them as large problems on the lake. Few respondents provided write-in answers. The most common write-in answers were reckless boating, shallow spots, rocks, and weeds.

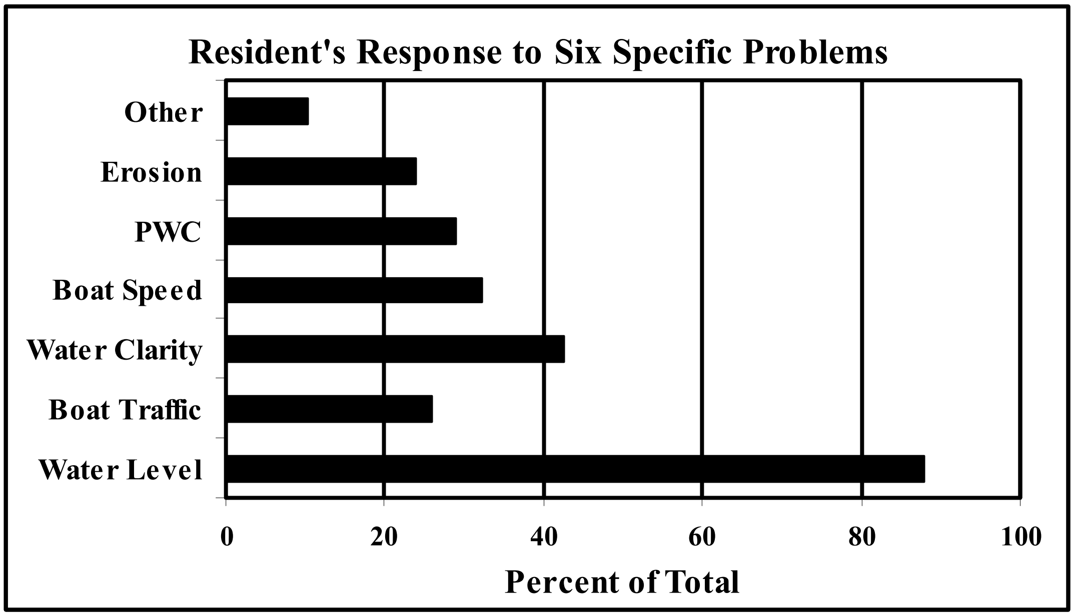

Figure 11. Percentage of surveyed lake residents responding to six specific issues as the problems at Bass Lake.

Although it ranked as the second biggest problem on the lake in the question referred to above, when residents were asked whether water clarity had increased, decreased, or remained unchanged over the years, respondents were nearly evenly split (Figure 12). Twenty-seven percent of the respondents noted that water clarity had increased or improved, while 32% of the respondents had noted that water clarity had decreased or gotten worse. Another thirty-two percent of the survey respondents reported no change in water clarity. Of those respondents who noted an increase in water clarity, most (79%) had observed this increase recently (over the past five years) (Figure 13). Most (65%) of those who reported a decrease in water clarity stated the decrease had occurred over the past ten years (Figure 14).

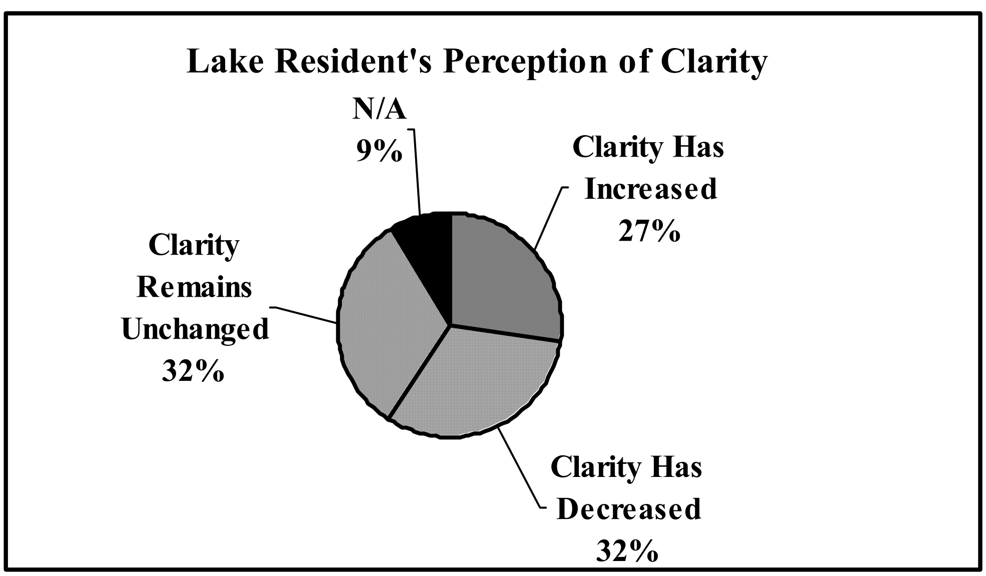

Figure 12. Lake residents' perception of changes in water clarity.

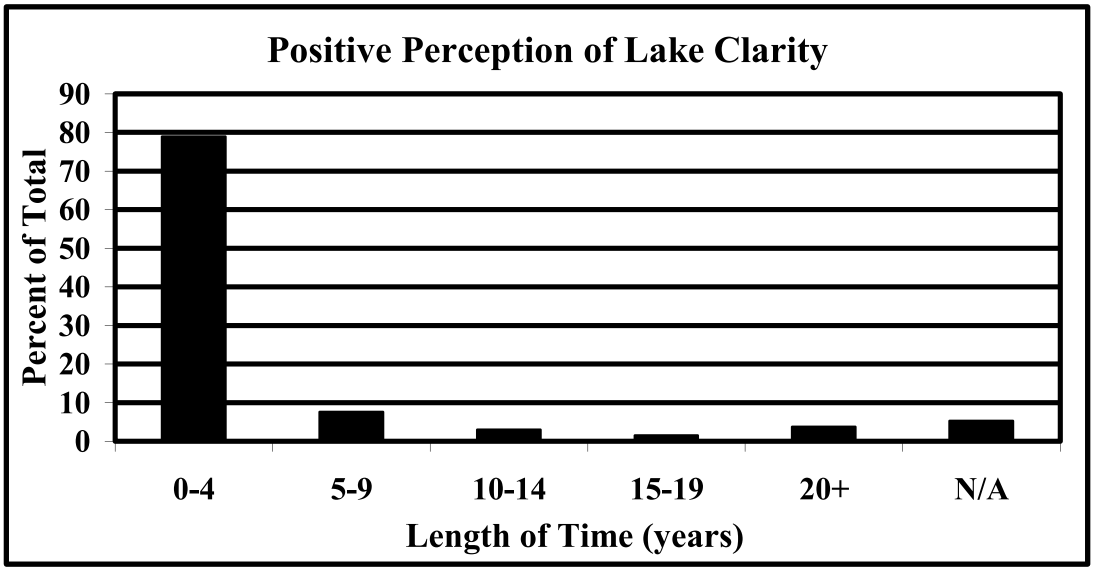

Figure 13. Length of time over which responding lake residents perceive that water clarity at Bass Lake has been improving.

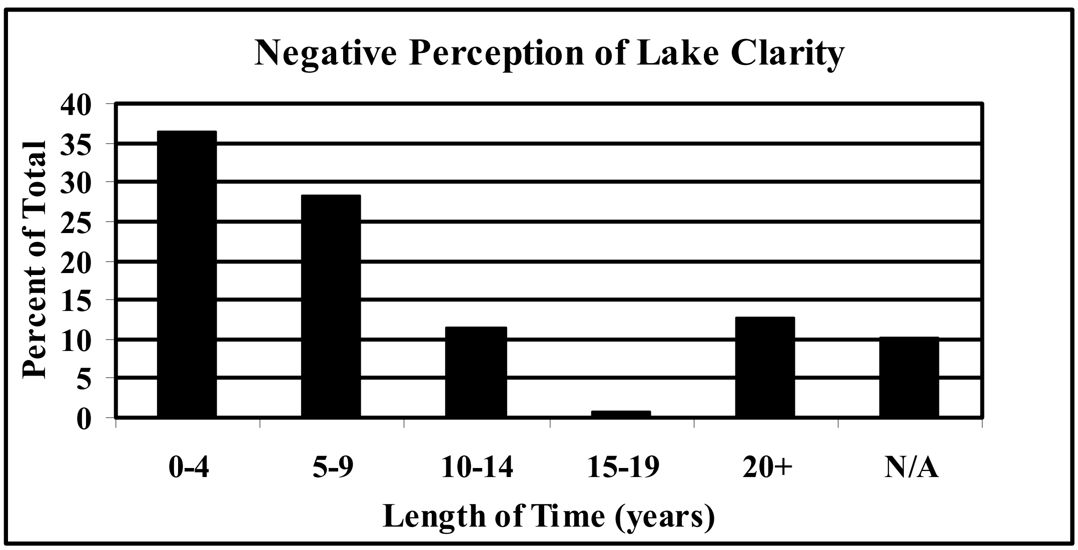

Figure 14. Length of time over which responding lake residents perceive that water clarity at Bass Lake has been deteriorating.

Respondents were more definitive when answering the survey question on the level of lake usage (Figure 15). Slightly less than 60% of the respondents believed there had been an increase in lake usage over the years. Fewer than 20% of the respondents noted a decrease in lake usage over the years, while approximately 15% saw no change in lake usage. Of those respondents who believed lake usage had increased over the years, most (64%) note this is a fairly recent (over the past ten years) increase (Figure 16). Of the twenty percent of the respondents reporting a decrease in lake usage, most (67%) percent believed the decrease had occurred over the past ten years (Figure 17).

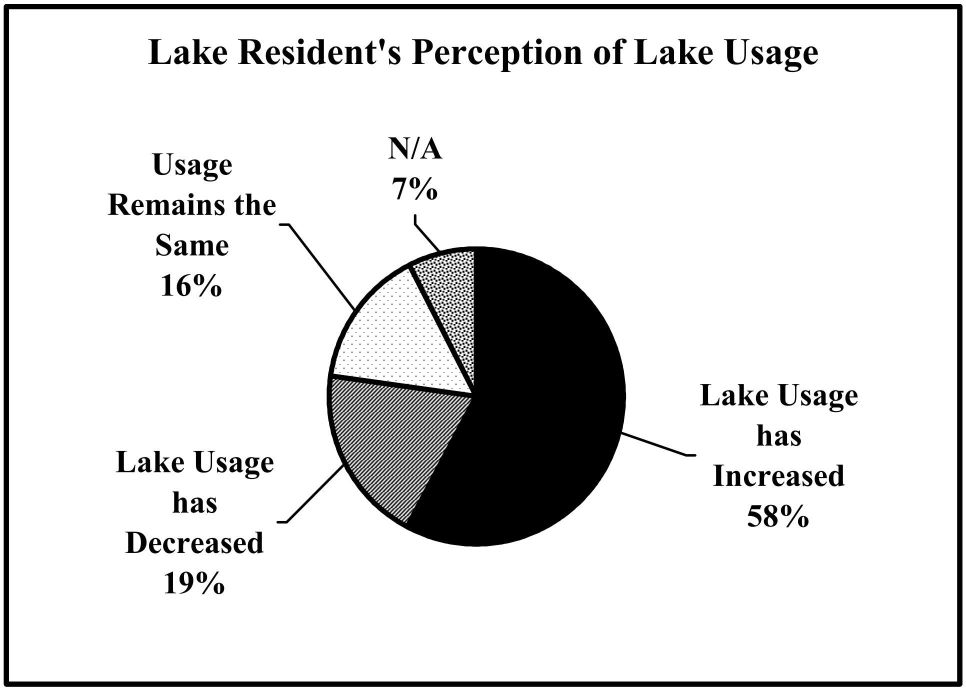

Figure 15. Responding lake residents' perception of changes in lake usage.

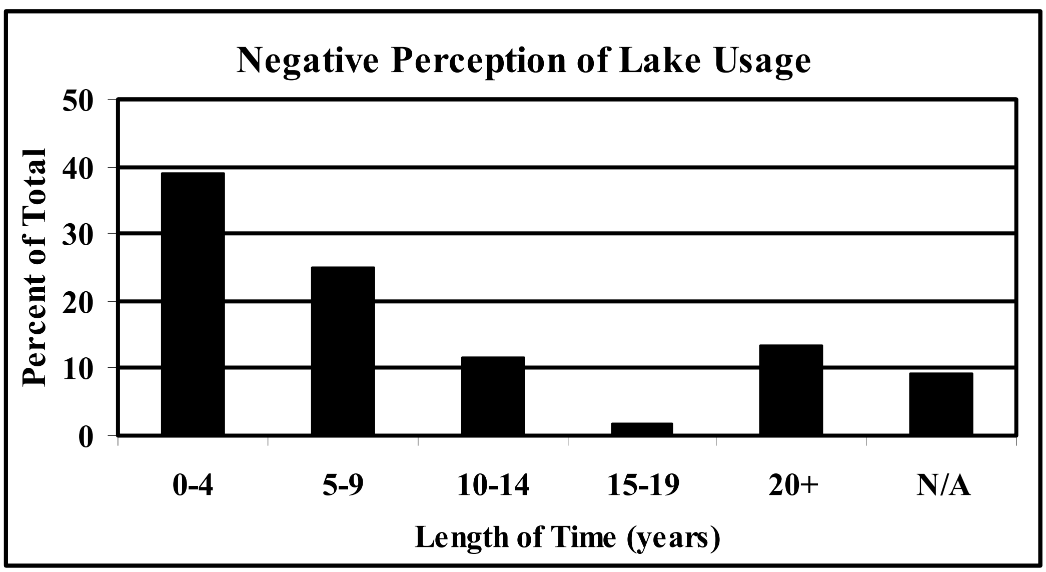

Figure 16. Length of time over which responding lake residents perceive that lake usage in Bass Lake has been increasing.

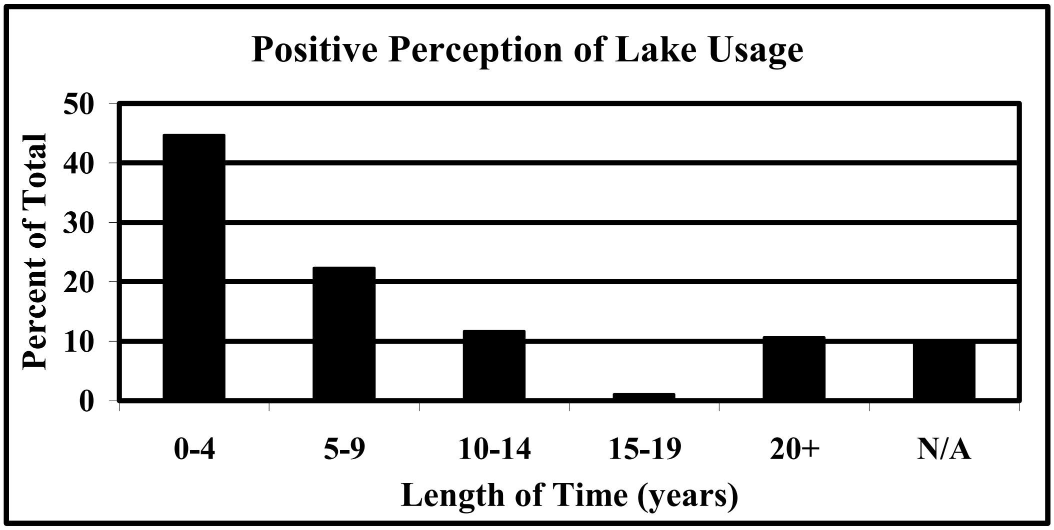

Figure 17. Length of time over which responding lake residents perceive that lake usage in Bass Lake has been decreasing.

The survey contained questions that elicited respondents' views on the rooted plant populations in the lake. When asked whether they view the vegetation on the lake as a problem, most respondents (55%) answered yes (Figure 18). Twenty-three percent of the respondents did not view the vegetation as a problem, while another 16% had no opinion on the matter. (No opinion was an option on the survey and should be differentiated from "no answer". Six percent of the respondents did not answer the question.) Residents were also asked whether the amount of vegetation was increasing, decreasing or had remained unchanged over the years (Figure 19). Thirty nine percent of the respondents felt the amount of vegetation in the lake was increasing. Seventeen percent of the respondents observed a decrease in the amount of vegetation, while 24% saw no change in the amount of vegetation in the lake. As with the questions on water clarity and lake usage, respondents were most likely to report vegetation changes (increases or decreases) occurred recently (over the past ten years).

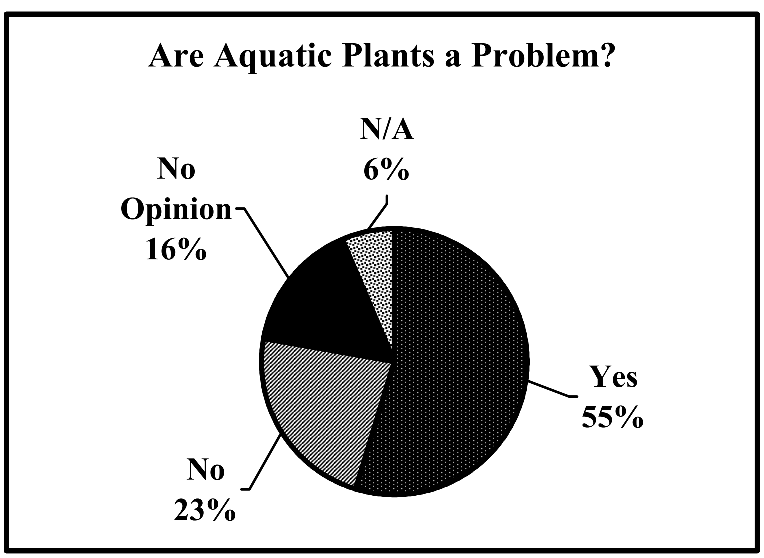

Figure 18. Lake residents' perception of aquatic plants in Bass Lake.

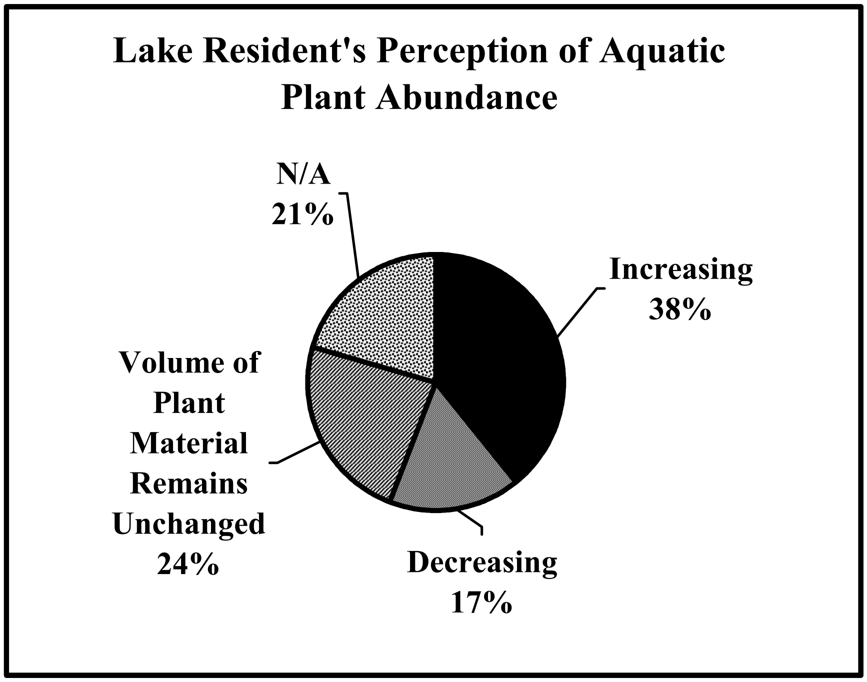

Figure 19. Lake residents' perception of changes in aquatic plant abundance.

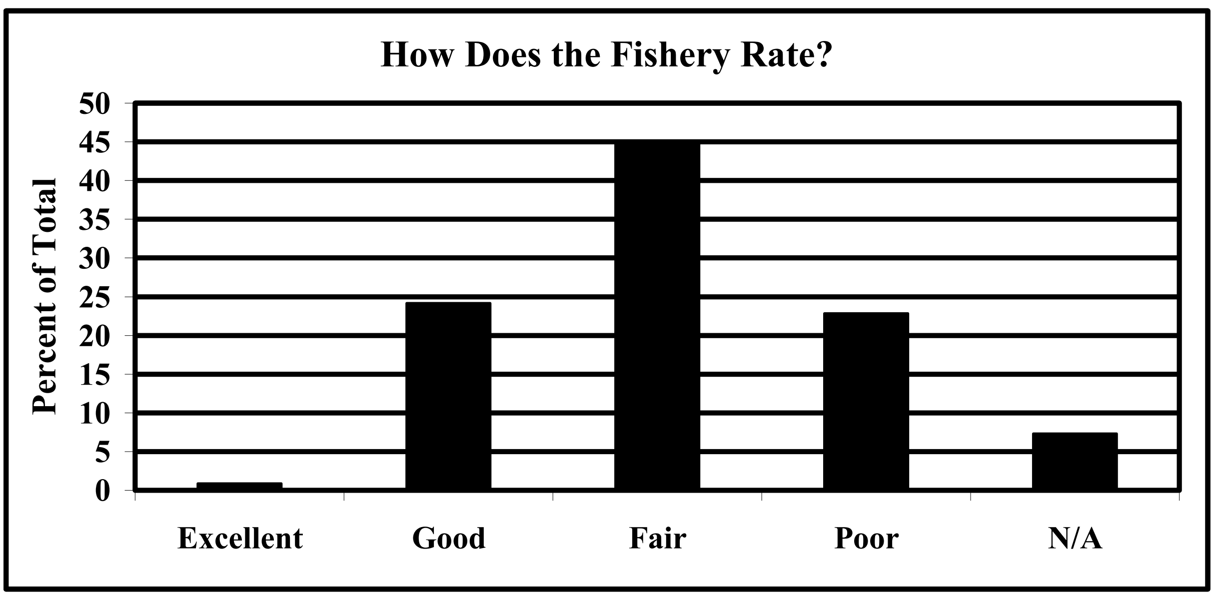

Figure 20. Rating of fisheries quality by surveyed lake residents expressed as percent of total.

The survey contained similar questions regarding the Bass Lake fishery. In general, Bass Lake anglers are not particularly impressed with the Bass Lake fishery. (The survey noted that only those who fished should answer the questions regarding the Bass Lake fishery.) When asked to rate the lake's fishery on a four-tier scale (excellent, good, fair, poor), most respondents (45%) placed Bass Lake in the "fair" category (Figure 20). Twenty four percent of the respondents classified Bass Lake as a "good" fishery, while 23% classified it as a "poor" fishery. Less than one percent of the respondents ranked the Bass Lake fishery as "excellent". When asked whether the fishing on Bass Lake has improved, declined, or remained unchanged over time, most respondents noted that the fishery had declined or remained unchanged (43% and 46% respectively) (Figure 21). Of those observing a decline in the fishery, most (60%) noted that the decline had occurred in recent years (over the past ten years) (Figure 22).

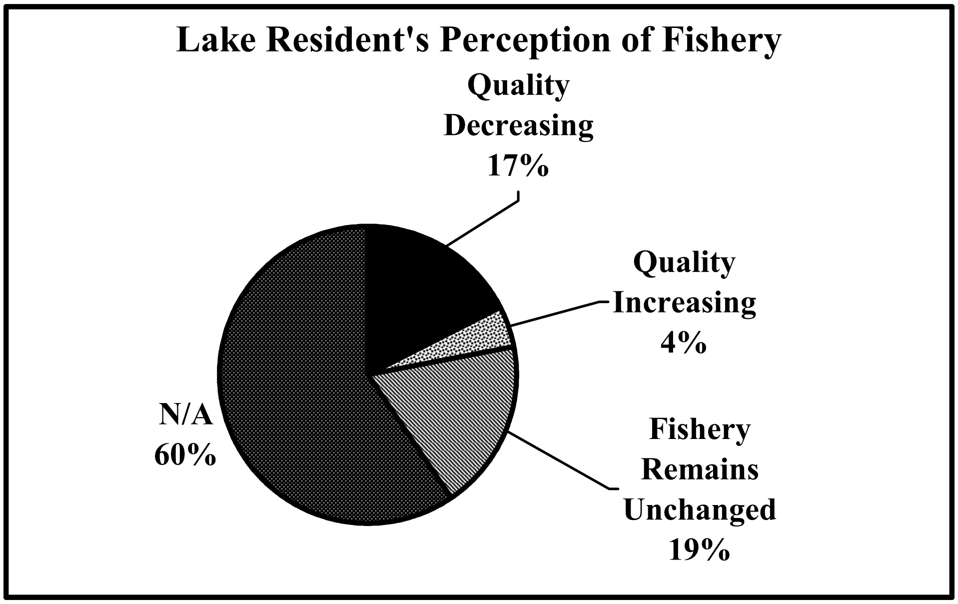

Figure 21. Perception of lake residents' regarding changes in Bass Lake's fisheries.

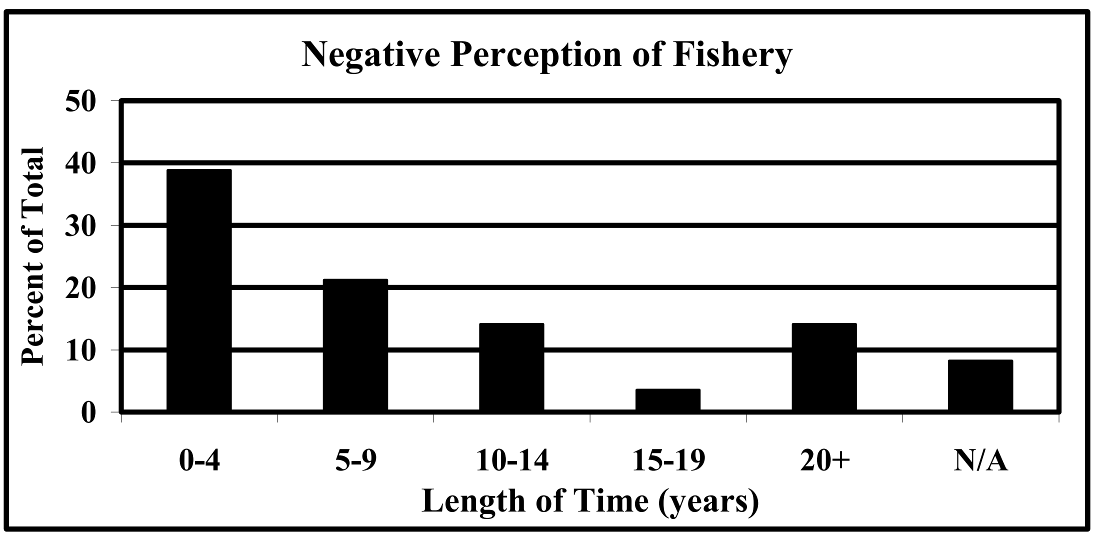

Figure 22. Length of time over which responding lake residents perceive that Bass Lake's fishery has been decreasing.

<u>Discussion</u>
While the survey provides good information on many characteristics of the lake and its uses, this discussion will concentrate on lake usage. The other portions of the survey will be addressed in

other sections of the document. (i.e. Residents' fishing preferences will be addressed more fully in the Fisheries section of this document.)

The resident survey suggests that local residents, as well as out-of-town users, regularly engage in a variety of activities on Bass Lake. This heavy use indicates the potential for conflict among lake users. Potential conflicts can be placed into two categories: 1. conflicts in which one use impairs or prohibits another use or 2. conflicts in which the physical, biological, and/or chemical composition of the lake impairs or prohibits a desired use of the lake. These categories are not mutually exclusive; some overlap exists. For example, use conflicts can arise when one use alters the physical, biological, and/or chemical composition of the lake such that the new lake condition impairs or prohibits a desired use of the lake.

Based on the resident survey suggests the potential for conflicts in which one use impairs or prohibits another use is fairly high. Lake residents listed swimming and boating as their favorite activities on Bass Lake. Unfortunately, power boating is incompatible with swimming for obvious safety reasons. Personal watercraft usage is similarly incompatible with swimming. In addition, the noise, air, and water pollution associated with power boating and personal watercraft usage may impair residents' ability to enjoy swimming in the lake. While many lake residents likely participate in both activities, the potential exists for boaters to feel there are too many swimmers present on a given day to boat as they would like. Conversely, swimmers may feel that boaters are impairing their enjoyment of the lake on a given day.

Similar use conflicts may exist between fishing and power boating. Lake residents ranked fishing as the third most popular activity on the lake. The noise and generation of wave energy associated with power boating and personal watercraft usage may negatively affect anglers' use and enjoyment of the lake resource. IDNR fisheries surveys indicate this type of conflict occurs regularly. Robertson (1991) states that "boating activity between Memorial Day and Labor Day is often so intense that many fishermen refrain from the sport rather than fight the boating traffic."

The shear number of motorized boats moored around Bass Lake highlights the potential for power boaters to limit one another's enjoyment of the lake. The resident boat count revealed that over 900 motorized boats are moored at the lake. IDNR creel surveys and lake resident counts at the boat launch reveal up to a third of the lake users at any time are from out-of-town. The heavy boat use on the lake may prevent some power boaters from boating where and at the speed they desire, thus impairing their use of the lake.

The lake's physical, biological, and/or chemical condition also impinges on resident and visitors' use of the lake. The most obvious example of this is how lake depth impacts recreational usage. The lake's shallowness prohibits high speed boating in certain areas for safety reasons. The lake's shallowness also forces swimmers further away from the shore to find water depths that actually allow swimming as opposed to wading. As swimmers extend their swimming spots out from the shore, this reduces the area available to power boaters and personal watercraft users.

Some lake activities can alter the lake's physical, biological, and/or chemical condition, impairing another use of the lake. The prime example of this is how motorized boating can impact other uses of the lake. Motorboats damage and sometimes destroy rooted plant beds. The destruction of rooted plant beds destroys fish resting and spawning habitat. Many of the most popular fish listed by resident in the survey utilize rooted plants during at least one life stage. For example, walleye fry require rooted plants for cover from predators before growing large enough to survive in the lake's open waters. Similarly, bluegill utilize vegetation for cover from predation; they also depend on the plants to serve as a substrate for their primary food, insects. Adult black crappie prefer to spawn in vegetated areas. Thus, boating practices that impair the rooted plant community ultimately impair fishing opportunities on the lake.

Power boating also decreases water clarity. As a shallow lake with a long fetch, Bass Lake is naturally susceptible to poor water clarity due to continual mixing of the bottom sediments within the water column. Power boating on Bass Lake only compounds the problem. Yousef et al. (1978) found that energy from a 75-hp motor can displace sediments as deep as 8 feet (2.4 m), which is greater than the average depth in Bass Lake. The problem is so severe at Bass Lake that it is not unusual for the lake to remain turbid for several days following a typical summer weekend (Bob Robertson, INDR Fisheries Biologist, personal communication).

This level of turbidity impacts other lake uses. For example, poor water clarity caused by resuspended sediments can decrease fishing opportunities on the lake. The resident survey and IDNR creel surveys indicate Bass Lake anglers prefer game species such as walleye and largemouth bass that are sight feeders. These fish species need clearer waters to feed and thus survive. Turbidity affects a fish species' ability to reproduce successfully. Some species, such as black crappie, require clearer waters for spawning. Regardless of the species, suspended sediment that settles on fish eggs can smother the eggs, destroying their viability. Ultimately, increases in turbidity will alter the fish community, favoring those species that are tolerant of the turbidity. If these tolerant species are not the ones preferred by anglers, use conflicts will arise.

Poor water clarity can also impact swimming and aesthetic uses of the lake. In a study of Minnesota lake users, Heiskary and Walker (1987) found that swimmers and aesthetic lake users start to perceive use impairment once Secchi disk depth is reduced to approximately 5 to 6 feet (1.5-1.8 m). Secchi disk depth is a measure of water clarity. (See the Water Quality section for a full discussion on the subject.) Bass Lake's historical and current Secchi disk measurements range between 1 and 4 feet (0.3-1 m). Thus, it is likely that swimmers and those who enjoy the aesthetic qualities at the lake feel the lake's turbidity impairs their use of the lake.

Given the likelihood for use conflict on Bass Lake, lake residents should work with all users (resident and non-resident) and sate officials to develop a recreational use management plan. Establishing timeframes for specific uses and setting aside specific areas on the lake for specific uses are the most common ways to manage recreational use of a lake. For example, residents could restrict motorized boat and personal watercraft use to the midday hours (9 AM to 5 PM) to allow for fishing and quiet enjoyment of the lake during the early morning and evening hours. This would reduce the potential conflicts between those who enjoy power boating and those who prefer to fish or simply take in the lake's quiet beauty.

Bass Lake already possesses some areas where certain uses are restricted. Its large no wake zone limits powerboat usage along the lake's shoreline. The public beach provides a swimming area where lake users can swim without having to worry about being in the way of a powerboater or water skier. Residents might consider enhancing some of these powerboat-restricted areas to improve the recreational opportunities in these areas. The resident survey suggests few individuals utilize the northwest corner of the lake's southern lobe. Planting native submerged plants would enhance fishing opportunities in this area. Because it is already in a use-restricted zone, the plantings would not conflict with other uses. Similarly, wave barriers could be used to protect swimmers at the public beach from turbulence caused by open water boaters or personal watercraft use.

Regardless of the specifics of the plan, good recreational use management plans contain several common characteristics:

1. The plan should include everyone in the lake community. The resident survey provides a good start to identifying the desired uses and perceptions of the Bass Lake community. However, as the boat count and IDNR creel surveys indicate, many non-residents utilize the lake as well. Non-resident users should also be given the opportunity to voice opinions during the development of a lake recreational management plan. Recreational management plans on public lakes are often voluntary in nature. Residents and non-residents are more likely to voluntarily comply with a plan they helped create.
2. The plan should recognize that lake users participate in a variety of activities on the lake and that sometimes these activities are in conflict with one another, either directly or indirectly. Although it will not be possible to please all users, a good plan strives to balance users' rights.
3. The plan should acknowledge the lake's current physical and ecological condition and recognize that the lake possesses certain ecological limitations. For example, Bass Lake is a shallow lake with a long fetch. As such, it is more susceptible to wind turbulence and the resulting decrease in water clarity than deeper lakes such as Lake Maxinkuckee. Given this starting condition, Bass Lake may be naturally less able to support heavy boating usage compared to other lakes in the region. Residents should consider this and other ecological limitations in developing a recreational use management plan.
4. The recreational use management plan should be part of an overall lake management plan.

WATERSHED PHYSICAL CHARACTERISTICS

Figure 23 is the United States Geological Survey topographical map for the Bass Lake area. The thin line of the map highlights the limits of the Bass Lake watershed. The watershed encompasses approximately 3061 acres or 4.78 square miles (1239.7 ha or 12.4 square km). Of this acreage, nearly half is open water (Bass Lake). Bass Lake possesses a watershed to lake area ratio of approximately 2.2:1. The relatively flat topography of the Bass Lake watershed is typical of much of Starke County. Relief ranges from approximately 725 feet (221 m) above MSL at the highest point in the watershed to approximately 710 feet (216 m) at the lakeshore.

Watershed size and watershed to lake ratios can affect the chemical and biological characteristics of a lake. For example, lakes with large watersheds have the potential to receive greater quantities of pollutants (sediments, nutrient, pesticides, etc.) from runoff than lakes with smaller watersheds. For lakes with large watershed to lake ratios, watershed activities can potentially exert a greater influence on the health of the lake than lakes possessing small watershed to lake

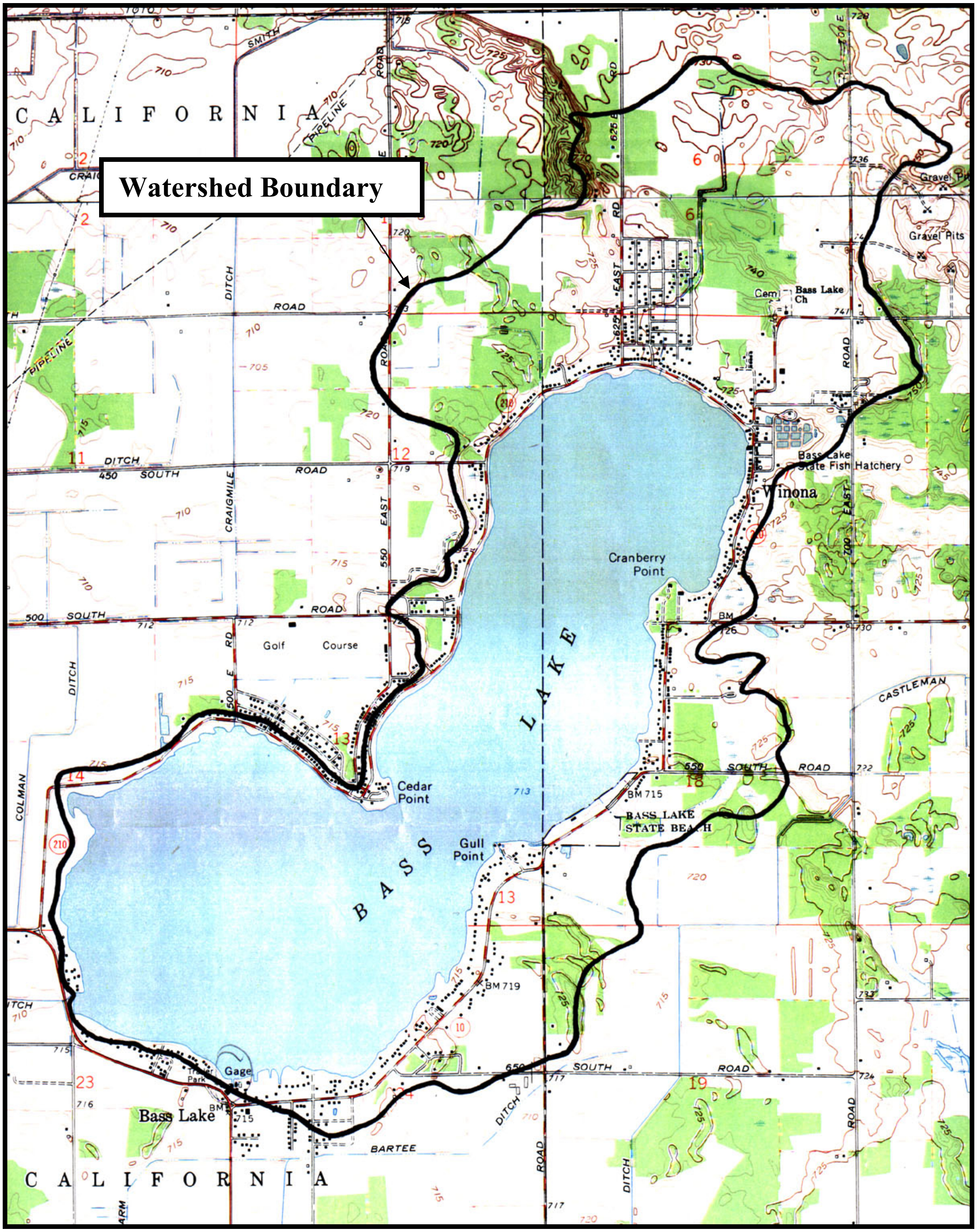

Figure 23. Topographical Map of the Bass Lake Watershed (Scale: 1"=2000'). Source of Base Map: U.S.G.S. 7.5 Minute Topographical Map

ratios. Conversely, for lakes with small watershed to lake ratios, shoreline activities may have a greater influence on the lake's health than lakes with large watershed to lake ratios.

For comparison, approximately 112 square miles (290 square km) of land drain to the 768-acre (311-ha) Lake Tippecanoe in Kosciusko County. This results in a watershed to lake ratio of approximately 93:1. As a result, Lake Tippecanoe's watershed can potentially exert a greater influence on the health of Lake Tippecanoe than the Bass Lake watershed can on Bass Lake. Conversely, since the shoreline area around Bass Lake accounts for a larger portion of its watershed, shoreline activities can potentially have a greater impact on the overall health of the Bass Lake than shoreline activities do to Lake Tippecanoe. Bass Lake's small watershed to lake ratio means that Bass Lake residents have more direct control over their lake's health than is typical.

CLIMATE

Indiana Climate

Indiana's climate can be described as temperate with cold winters and warm summers. The National Climatic Data Center provides an excellent summary of Indiana weather in its 1976 Climatology of the United States document No. 60. "Imposed on the well known daily and seasonal temperature fluctuations are changes occurring every few days as surges of polar air move southward or tropical air moves northward. These changes are more frequent and pronounced in the winter than in the summer. A winter may be unusually cold or a summer cool if the influence of polar air is persistent. Similarly, a summer may be unusually warm or a winter mild if air of tropical origin predominates. The action between these two air masses of contrasting temperature, humidity, and density fosters the development of low-pressure centers that move generally eastward and frequently pass over or close to the state, resulting in abundant rainfall. These systems are least active in midsummer and during this season frequently pass north of Indiana" (National Climatic Data Center, 1976). Prevailing winds are generally from the southwest, but are more persistent and blow from a northerly direction during the winter months.

Starke County Climate

The climate of Starke County is characterized as cool and humid with winters that typically provide enough precipitation, in the form of snow, to supply the soil with sufficient moisture to minimize drought conditions when the hot summers begin. Winters are cold, averaging 27ºF (-3ºC), while summers are warm, averaging 72ºF (22ºC). The highest temperature ever recorded was 109ºF (43ºC) on June 20, 1953. Mild drought conditions do occur occasionally during the summer when evaporation is highest. Average relative humidity differs very little over the course of a day and is often 100 percent during summer months. In 2001, just over 40 inches (103 cm) of precipitation (Table 2) was recorded at Plymouth, Indiana in Marshall County (http://shadow.agry.purdue.edu/sc.index.html). The average annual precipitation is 38.52 inches (97.8 cm). Although the difference between the annual total precipitation in 2001 compared to the annual average is not drastic, the year was characterized by significant wetter-than-normal and drier-than-normal periods. During 2001, the months of February and October received two inches (5 cm) and five inches (13 cm) more than normal, respectively. However, January, March and December each saw less than normal amounts of precipitation.

Table 2. Monthly rainfall data for year 2001 as compared to average monthly rainfall. Averages are based on available weather observations taken during the years of 1961-1990. (http://shadow.agry.purdue.edu/sc.index.html).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	TOTAL
2001	0.78	4.53	0.83	2.94	3.84	4.00	4.78	3.56	3.04	8.80	1.99	1.55	40.64
Average	1.92	1.84	2.87	3.87	3.79	4.20	4.10	3.33	3.62	3.02	3.03	2.93	38.52

GEOLOGIC FRAMEWORK

Bass Lake occurs in what is known as the "Eolian Sands Aquifer System" which is characterized by a thick layer of windblown sand overlying a semi-continuous clay-rich deposit of glacial till. Additional deposits of sand and gravel underlie the clay-rich till deposit. In an effort to develop a detailed geological model of the area around Bass Lake, the iLITH data base (edited water well logs from the archives of the Department of Natural Resources Division of Water) was searched for all available bore hole lithologic records. The locations of the available lithologic logs are shown as blue and red dots in Figure 24. The red dots are numbered and the materials encountered at those locations are depicted as colors in Figure 25.

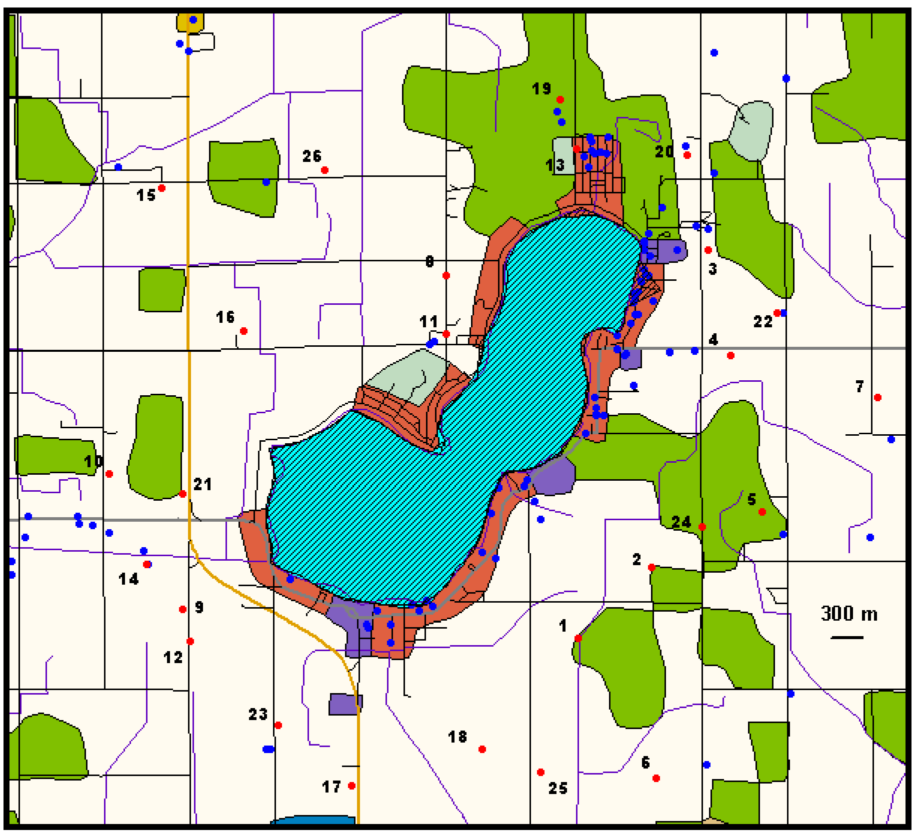

Figure 24. Map showing locations of water wells (blue and red dots) with lithologic descriptions available in the iLITH data base developed by glacial geologists at the Indiana Geological Survey. The iLITH data base is a set of edited well logs that were derived from the complete set of drillers logs archived by the Division of Water (Indiana Department of Natural Resources). The red dots are numbered and correspond to the lithologic logs depicted in Figure 25.

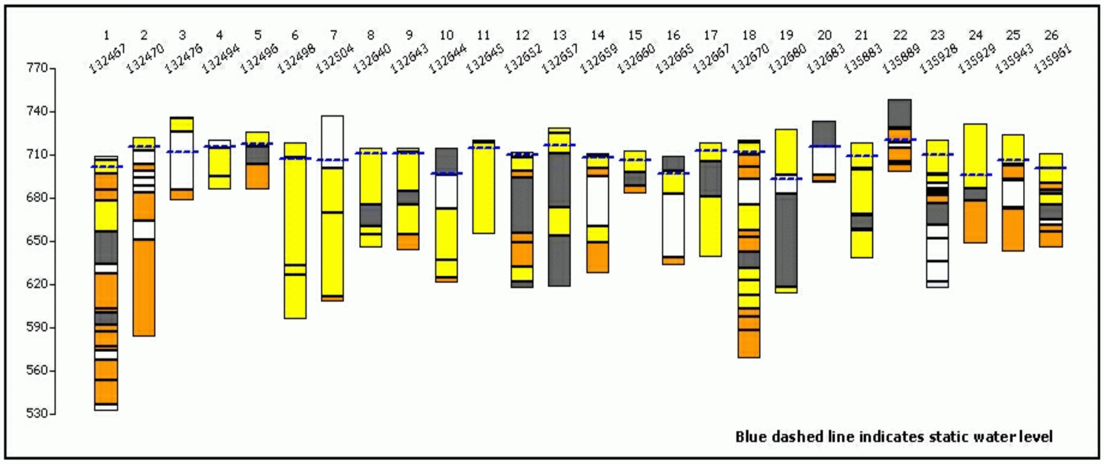

Figure 25. Selected lithologic logs of near surface materials at locations surrounding Bass Lake. The location of each log can be determined by matching the log number (top line of graph) with the numbered red dot in Figure 24. Key: yellow=sand, orange=gravel, gray=clay, white=uncertain. Note the lack of clay in several of the depicted logs.

The most notable characteristic of the logs is that while a clay layer (gray color) occurs in most of the well logs, it is not found in all of them. The implication is that the upper (windblown sand) and lower (sand and gravel) aquifers are not completely isolated from one another by an extensive layer of clay. This finding is important for Bass Lake since lake residents pump water from the lower aquifer to their lake in an effort to raise the lake's water level. It is possible (though not yet proven) that long term pumping of the deeper sands and gravel will eventually have an effect on water levels in the upper aquifer.

A more detailed analysis of the geologic framework of the area was undertaken using methods of statistical kriging and visualization software. The CD-ROM attached to this document contains two audio-visual interlaced files (AVI's). This AVI's present an automated representation of Bass Lake's subsurface geology. Refer to Appendix B for supporting explanatory material prior to viewing the AVI's.

SOILS

The soil types found in the Bass Lake Watershed are a product of the original parent material deposited by the glaciers that covered this area 12,000 to 15,000 years ago. As glaciers moved over the watershed, they laid layers of clay-rich till over the watershed's landscape. Meltwaters from receding glaciers carried sand and outwash materials to the watershed. The repeated cycled of glacier advance and retreat resulted in the watershed's layered geology described above. The interaction of the clay till and sandy glacial deposits with the physical, chemical and biological variables found in the area (climate, plant and animal life, time and the physical and mineralogical composition of the plant material) formed the soils covering the Bass Lake watershed today.

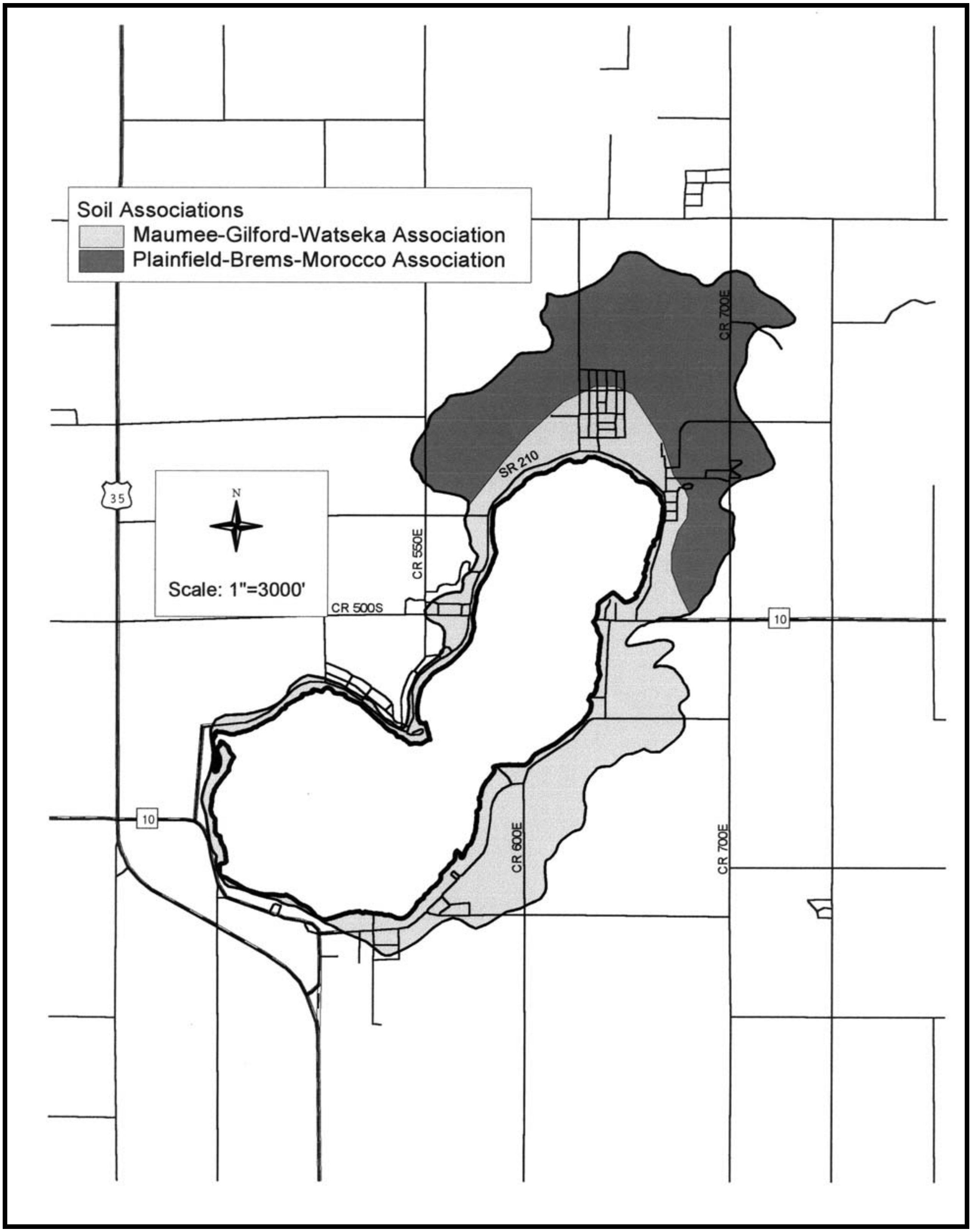

Figure 26. Major soil associations map of the Bass Lake watershed based on the NRCS Soil Survey for Starke County (Barnes, 1982). Source of Base Map: U.S.G.S. 7.5 Minute Topographical Map.

The Bass Lake watershed lies within two major soil associations. Soils in the upper (northeast) portion of the watershed belong to the Plainfield-Brems-Morocco association, while the lower portion of the watershed surrounding the lake lies in the Maumee-Gilford-Watseka association (Figure 26). These soil association are the most common soil associations in Starke County; combined they cover approximately 75% of the county (Barnes, 1982).

The Plainfield-Brems-Morocco association consists of nearly level to strongly sloping soils. These soils developed from sandy deposits in outwash plains. In general, Plainfield soils account for roughly 42% of the total soils in the association; Brems soils account for 17%, while Morocco soils make up 16% of the association. Plainfield soils typically occupy higher areas of the landscape, while Morocco soils lie in lower areas. The association's soils range from excessively drained (Plainfield soils) to somewhat poorly drained (Morocco). Barnes (1982) notes that soils in this association are generally unsuitable for cultivated crops due to their droughtiness and vulnerability to wind blown erosion.

As the topography of the watershed levels near Bass Lake, the soils shift from the Plainfield-Brems-Morocco association to the Maumee-Gilford-Watseka association. Like the soils of the Plainfield-Brems-Morocco association, Maumee-Gilford-Watseka association soils developed from sandy deposits in outwash plains. Approximately one third of the Maumee-Gilford-Watseka association consists of Maumee soils. Twenty eight percent of the soils in the association are Gilford or Watseka soils. Maumee and Gilford soils occupy low depressional areas on the landscape, while Watseka soils are found at slightly higher elevations. Soils in the Maumee-Gilford-Watseka association range from very poorly drained to somewhat poorly drained. This characteristic makes soils in this association generally unsuitable for building and limits their ability to serve as a septic tank absorption field.

Highly Erodible Soils

The Bass Lake watershed does not contain any mapped soil units that fit the Natural Resources Conservation Serves (NRCS) definition of highly erodible. Several areas meet the NRCS definition of potentially highly erodible soils. Figure 27 maps the presence of potentially highly erodible soils in the Bass Lake watershed. (It is important to note that this map is based on the Natural Resources Conservation Service (NRCS) criteria for erodible soils and is not field checked.) Approximately 57 acres (23 ha) of land are mapped as potentially highly erodible soils. This acreage is scattered throughout the northern and eastern portion of the watershed, with most of the acreage located to the north of the lake. As expected most of the potentially highly erodible soils lie within the Plainfield-Brems-Morocco association (Figure 26). Conservation methods and best management practices should be utilized when these soils are disturbed. This includes residential development as well as farming practices.

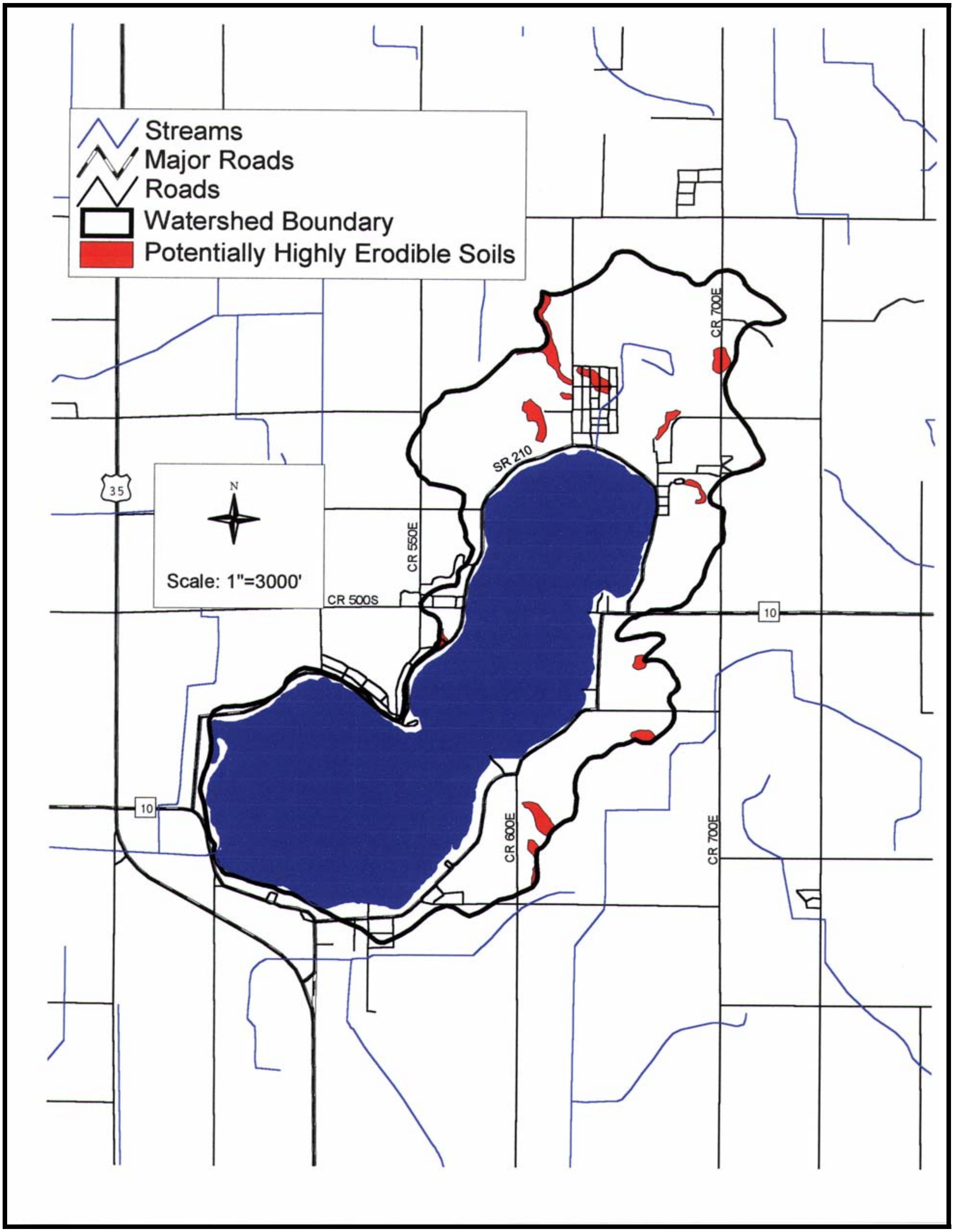

Figure 27. Potentially highly erodible soils in the Bass Lake watershed. Source of Base Map: U.S.G.S. 7.5 Minute Topographical Map.

Prior to the creation of the Bass Lake Conservancy District and installation of a sanitary sewer system around the lake in the late 1980's and early 1990's, individual septic tanks and septic tank absorption fields accepted and treated sanitary waste from lake residences. As mentioned above, the lake's shoreline lies in the Maumee-Gilford-Watseka soils association which consists of soils that are generally unsuitable for use as a septic leach field. Poor treatment of septic effluent by the soil combined with the high water table near the lake likely resulted in the release of pollutants (nutrients and pathogens) to the lake. The installation of the sanitary sewer system curtailed much of the pollutant loading from septic systems. However, residual pollutants may still be present in the soils surrounding Bass Lake. Release of these residual pollutants can impair water quality, although it is unlikely that any residual septic system pollutants contribute significantly to the overall pollutant load to the lake.

Soils in the watershed, and particularly their ability to erode or sustain specific land use practices, can impact the water quality of a lake. For example, highly erodible soils are, as their name suggests, easily erodible. Soils that erode from the landscape are transported to waterways or waterbodies where they impair water quality and often interfere with recreational uses by forming sediment deltas in the waterbodies. In addition, such soils carry attached nutrients, which further impair water quality by fertilizing macrophytes (rooted plants) and algae.

LAND USE

Figure 28 and Table 3 present land use information for the Bass Lake watershed. Land use data was obtained from the Indiana Gap Analysis Project. This data was checked with recent aerial photography and, in some areas, field checked. Data was then corrected to reflect current conditions in the watershed.

Bass Lake occupies a large portion of the watershed covering over 1400 acres (580 ha) or nearly half of the watershed. Much of the remaining portion of the watershed is in forested land or residential use; forested land and residential areas account for nearly 21% and 15% of the land use in the watershed, respectively. Row crops, wetlands, and pastures cover only a small portion of the watershed.

Table 3. Land use in the Bass Lake watershed.

Land Use	Area (acres)	Area (hectares)	Percent of Watershed
Forested	642.3	259.9	21.0
Residential/Urban	457.6	185.2	15.0
Row Crop	291.9	118.1	9.5
Wetland	165.4	66.9	5.4
Pasture	64.4	26.1	2.1
Open Water	1437.2	581.6	47.0
Total	**3060.9**	**1238.7**	**100%**

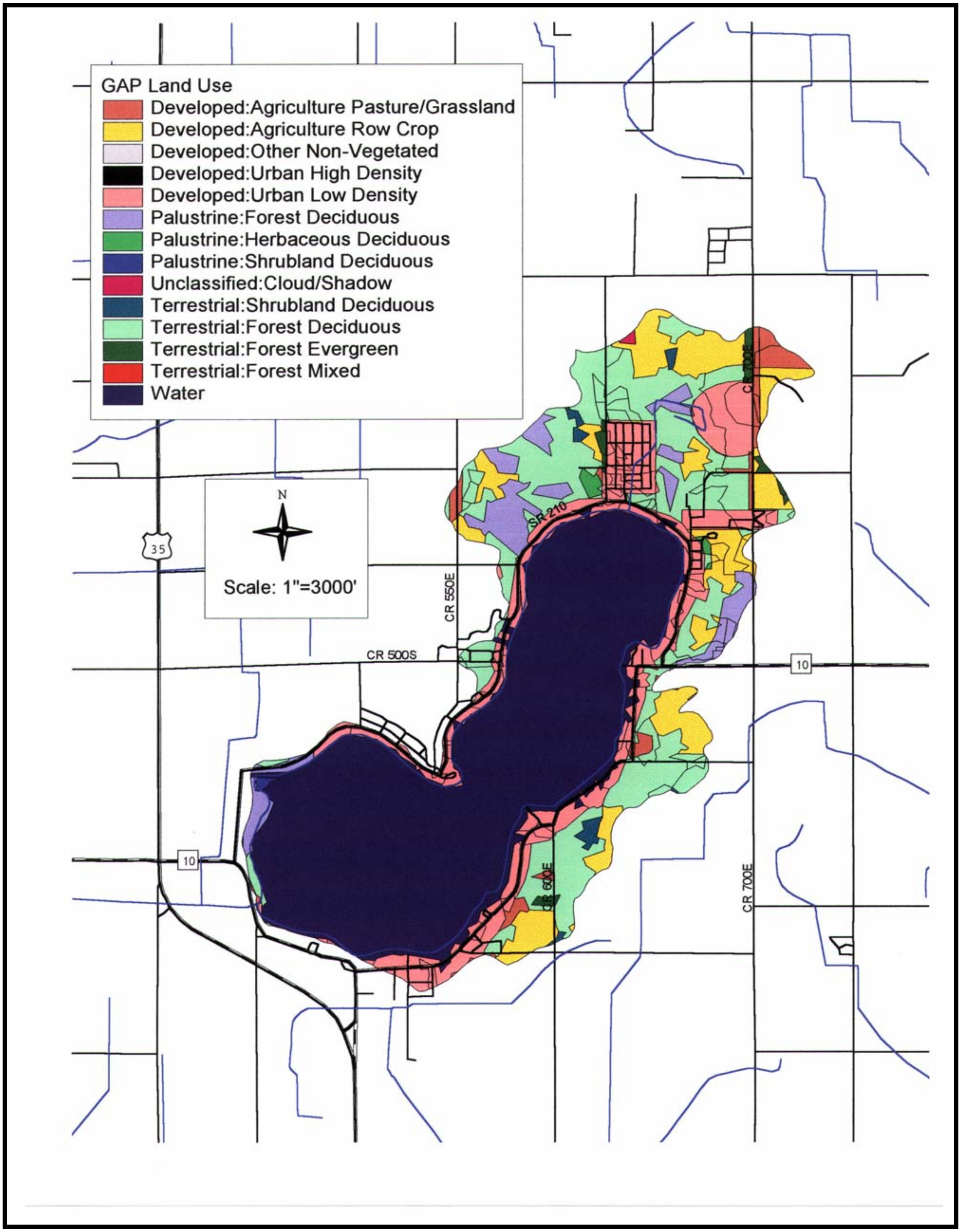

Figure 28. Land use in the Bass Lake watershed. Source of Base Map: U.S.G.S. 7.5 Minute Topographical Map; Source of Data: Indiana GAP Analysis.

WETLANDS

Because wetlands perform a variety of functions in a healthy ecosystem, they deserve special attention when examining watersheds. Functioning wetlands filter sediments and nutrients in runoff, store water for future release, provide an opportunity for groundwater recharge or discharge, and serve as nesting habitat for waterfowl and spawning sites for fish. By performing these roles, healthy, functioning wetlands often improve the water quality and biological health of streams and lakes located downstream of the wetlands. The land use table above (Table 3) indicates that wetlands cover approximately 5.4% of the Bass Lake watershed. Table 4 presents the acreage of wetlands by type. Figure 29 maps the wetlands in the Bass Lake watershed by type.

Table 4. Acreage and classification of wetland habitat in the Bass Lake watershed.

Wetland Type	Area (acres)	Area (hectares)	Percent of Watershed
Forested	152.4	61.7	92.6
Shrubland	3.0	1.2	1.8
Herbaceous	10.0	4.0	6.0
Total	**165.4**	**66.9**	**100%**

Source: Indiana Gap Analysis Project

The IDNR estimates that approximately 85% of the state's wetlands have been filled (Indiana Wetland Conservation Plan, 1996). The greatest loss has occurred in the northern counties of the state such as Starke County. The last glacial retreat in these northern counties left level landscapes dotted with wetland and lake complexes. Development of the land in these counties for agricultural purposes altered much of the natural hydrology, eliminating many of the wetlands. Shoreline development around lakes has also reduced wetland acreage.

To estimate the historical coverage of wetlands in the Bass Lake watershed, hydric soils in the watershed were mapped in Figure 30. (As noted for the potentially highly eroded soils map, this map is based on the Natural Resources Conservation Service criteria for hydric soils and is not field checked.) Because hydric soils developed under wet conditions, they are a good indicator of the historical presence of wetlands. Comparing the total acreage of wetland (hydric) soils in the watershed (715 acres or 289 hectares) to the acreage of existing wetland (165 acres or 67 ha) suggests that only 23% of the original wetland acreage exists today. Much of the loss occurred along the lake's shoreline.

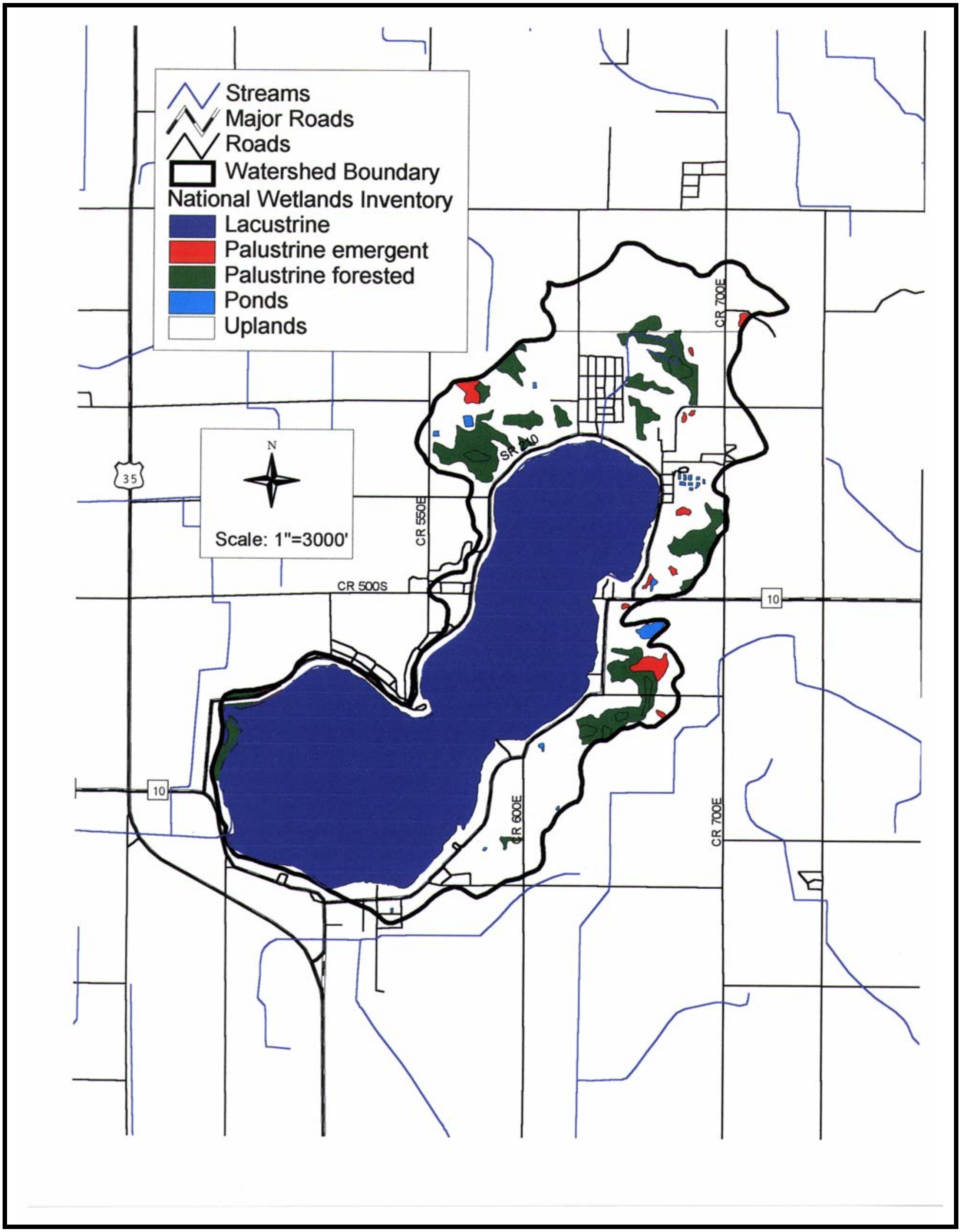

Figure 29. National Wetlands Inventory map of the Bass Lake watershed. Source of Base Map: U.S.G.S. 7.5 Minute Topographical Map.

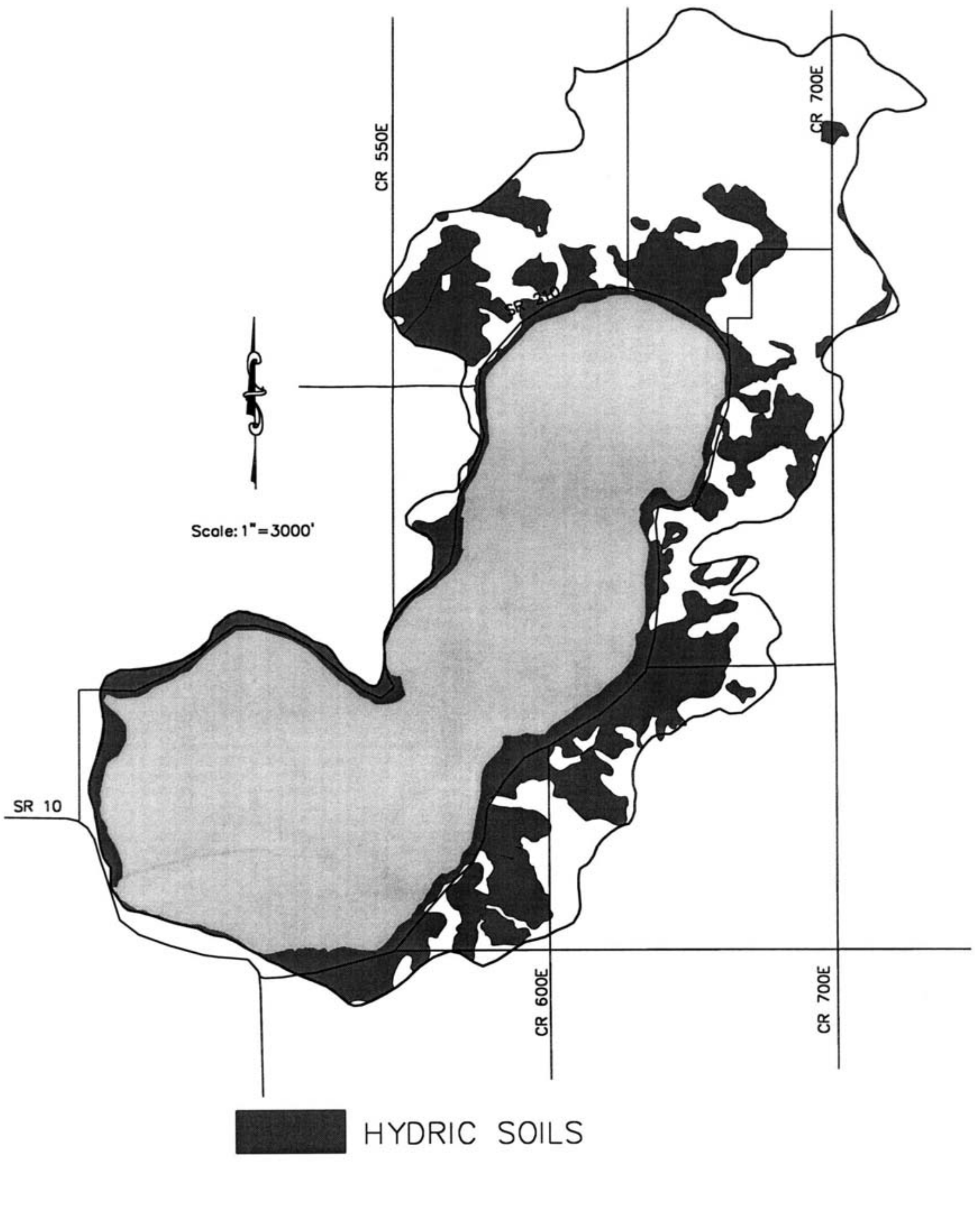

Figure 30. Hydric soil map of the Bass Lake watershed based on the NRCS Soil Survey for Starke County (Barnes, 1982). Source of Base Map: U.S.G.S. 7.5 Minute Topographical Map.

NATURAL COMMUNITIES AND ETR SPECIES

The Indiana Natural Heritage Data Center database provides information on the presence of endangered, threatened, or rare species, high quality natural communities, and natural areas in Indiana. The database was developed to assist in documenting the presence of special species and significant natural areas and to serve as a tool for setting management priorities in areas where special species or habitats exist. The database relies on observations from individuals rather than systematic field surveys by the Indiana Department of Natural Resources. Because of this, it does not document every occurrence of special species or habitat. At the same time, the listing of a species or natural area does not guarantee that the listed species is currently present or that the listed area is in pristine condition. The database includes the date that the species or special habitat was last observed and reported in a specific location.

Results from the database search for the Bass Lake watershed are presented in Appendix C. (For additional reference, a listing of endangered, threatened, and rare species and high quality natural communities documented in Starke County is included in Appendix D.) According to the database, Bass Lake, its watershed, and the area immediately adjacent to the watershed support a variety of endangered, threatened, and rare animals and plants. The listed animals include three reptiles, the spotted turtle (*Clemmys guttata*), the eastern mud turtle (*Kinosternon subrubrum*) and the slender grass lizard (*Ophisaurus attenuatus*). All of the listed plants are hydrophytic plants, likely remnants from the original marshes that bordered the lake. Most of the database entries, including the only high quality community, are found in or near the southern portion of the watershed in Sections 14 and 24, Township 32 North, Range 2 West (Figure 31).

Four of the database entries are relatively recent. Torrey's bulrush (*Scirpus torreyi*) was last noted in 1987, reticulated nutrush (*Scleria reticularis*) in 1987, jointed sedge (*Carex straminea*) in 1989 and the sessile-leaved bugleweed (*Lycopus amplectens*) in 1977. The remaining entries in the database possess observed dates before 1950. Some observations date back to the 1910's and 1920's. Given the agricultural and residential development that has occurred in the watershed since the early part of the century, it is unlikely that many of the endangered, threatened, and rare species listed in the database still inhabit the area.

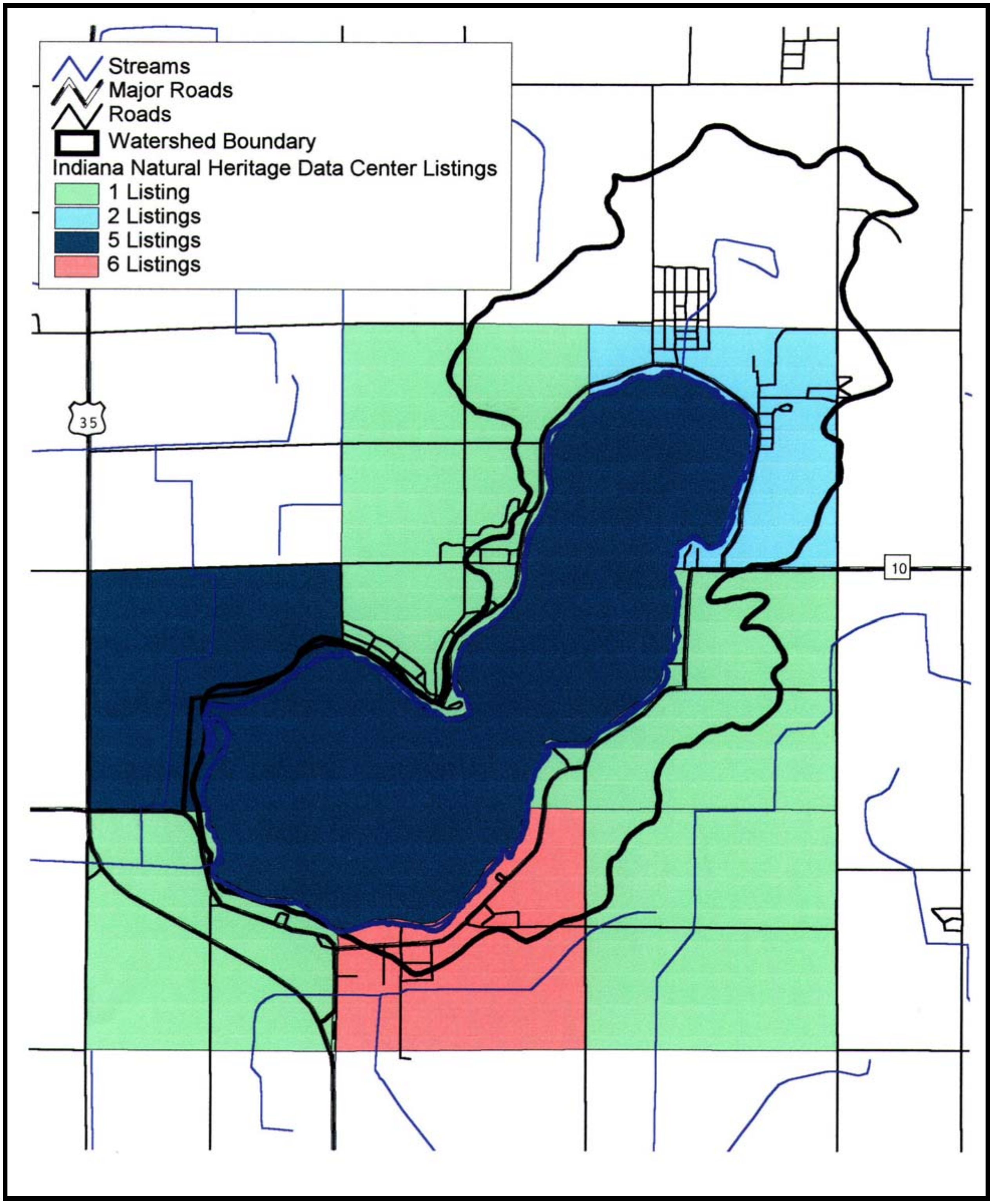

Figure 31. Locations of endangered, threatened or rare species or habitat observed in the Bass Lake watershed. Source of Base Map: U.S.G.S. 7.5 Minute Topographical Map; Source of Data: IDNR Division of Nature Preserves.

HYDROLOGIC CONDITIONS

The U.S. Geological Survey (USGS) has assembled a continuous record of lake stage. Figure 32 graphically depicts this record. According to the records of the USGS, the current legal level of the lake is 13.65 ft (local stage), which corresponds to an elevation of 713.48 ft above mean sea level. Although the lake is at or above the legal level much of the time, there are extended periods when the lake is below the legal level. The longest period of low levels occurred in the mid 1960's and that led to the installation of a 110-foot well that could be used to pump as much as 3 million gallons of groundwater per day from the deep aquifer into the lake (Beaty, 1990, p.75). A probability analysis of the measured lake levels indicates that the most probable lake level is about equal to the legal lake level but that the lake is below the legal level at least half of the time (Figure 33).

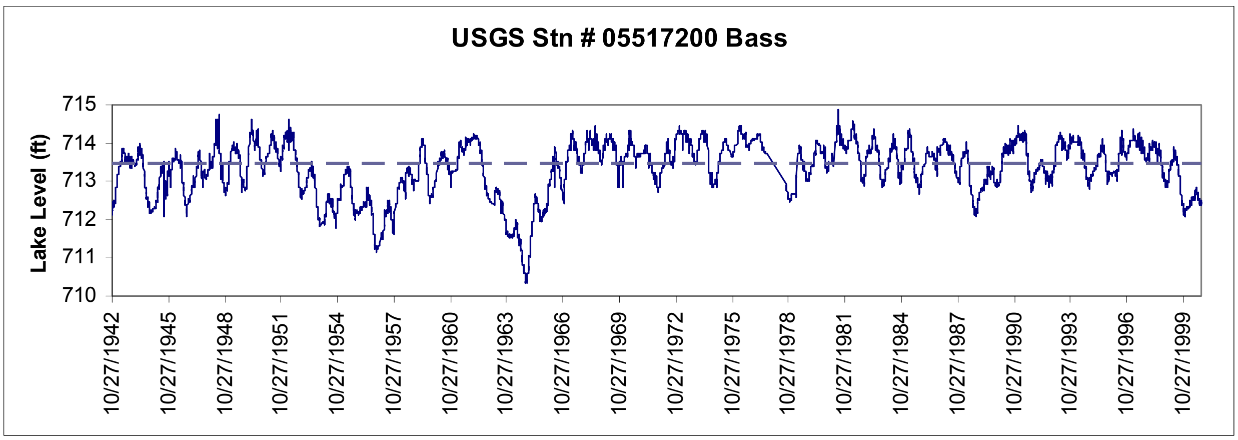

Figure 32. Continuous record of Bass Lake water levels compiled by the U.S. Geological Survey. Dashed line is the established legal level of 713.48 ft above sea level. Note that levels were lower than those observed in 2000 at several times in the past 50+ years.

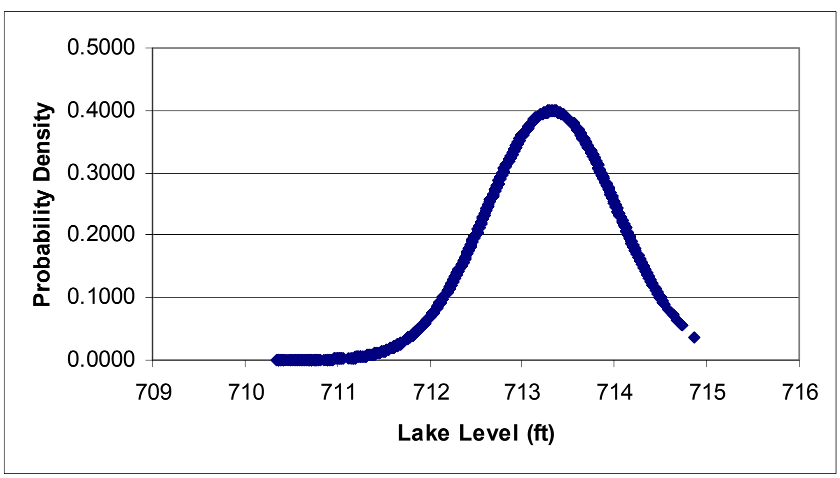

Figure 33. Statistical frequency distribution of Bass Lake water levels based on data compiled by the U.S. Geological Survey.

The bathymetry of the lake is not conducive to maintaining a consistently large lake area. The lake is spoon-shaped with the shallow end to the southwest. This leads to a relationship between lake level and lake area that is exponential (Figure 34). A drop in the lake level of just 3 feet (0.9 m) results in a reduction over one-third of its area.

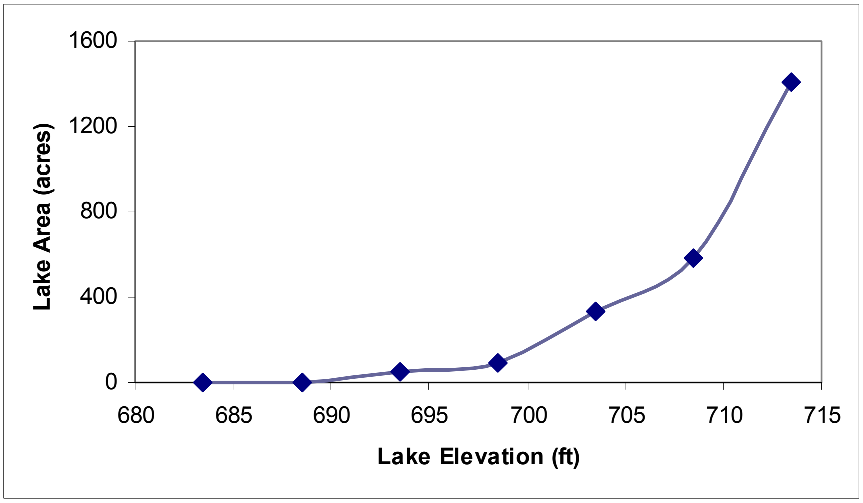

Figure 34. Area of Bass Lake as a function of lake surface elevation. Note that the trend of the data is exponential indicating a very large change in area resulting from a small change in the elevation of the water surface.

Bass Lake is situated along a groundwater flow divide. The dunes to the east and southeast of the lake serve both as a groundwater divide and a recharge area for the lake. Groundwater flow is from southeast towards the northwest. Records of water levels in wells monitored by the Indiana Department of Natural Resources Division of Water (IDNR-DOW) in the mid 1980's support this conclusion. The data in Figure 35 show that water levels in the elevated dunes area (up gradient) are consistently well above the level of the lake. In contrast, the data in Figure 36 show that most of the time, the water levels in the sandy plain to the northwest of the lake (down gradient) are lower than the lake level. Together, these data indicate that the flow of groundwater is from the dunes (recharge area) through the lake and towards the Yellow and Kankakee Rivers (discharge area). Fortunately, the hydraulic gradient between the dunes and the lake is much steeper than the gradient that exists between the lake and adjacent plain, so there is normally a net gain of water due to groundwater flow across the area of the lake.

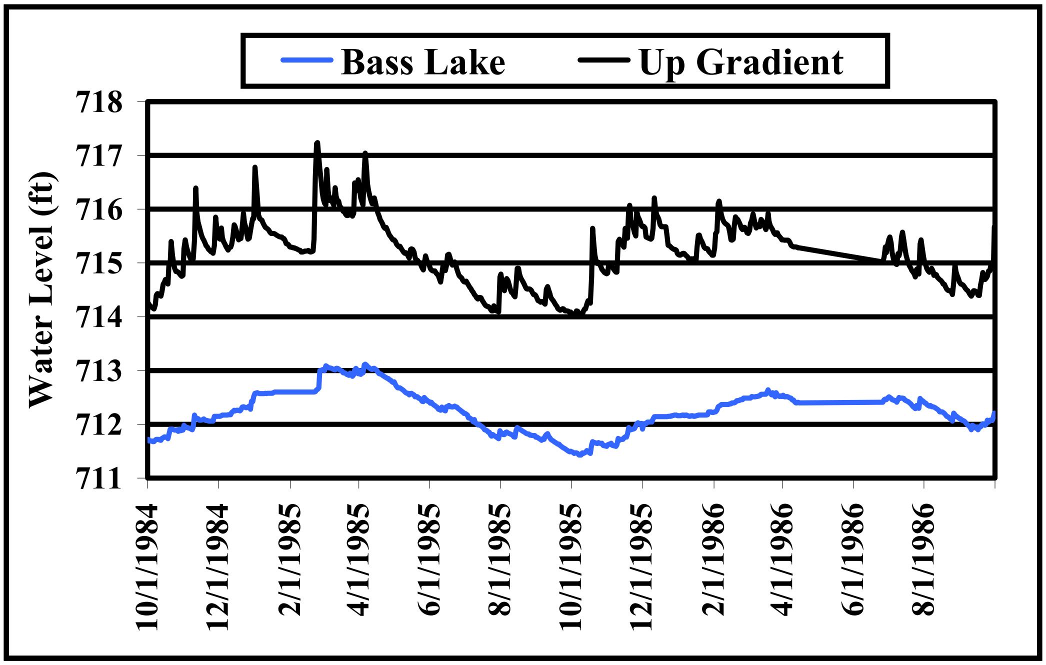

Figure 35. Water levels in a monitoring well located in the dunes on the southeast edge of Bass Lake in relation to the level of the lake surface (from records of IDNR-DOW). Note that the water levels in the elevated dunes are consistently 2 to 3 feet (0.6-0.9 m) higher than the lake level.

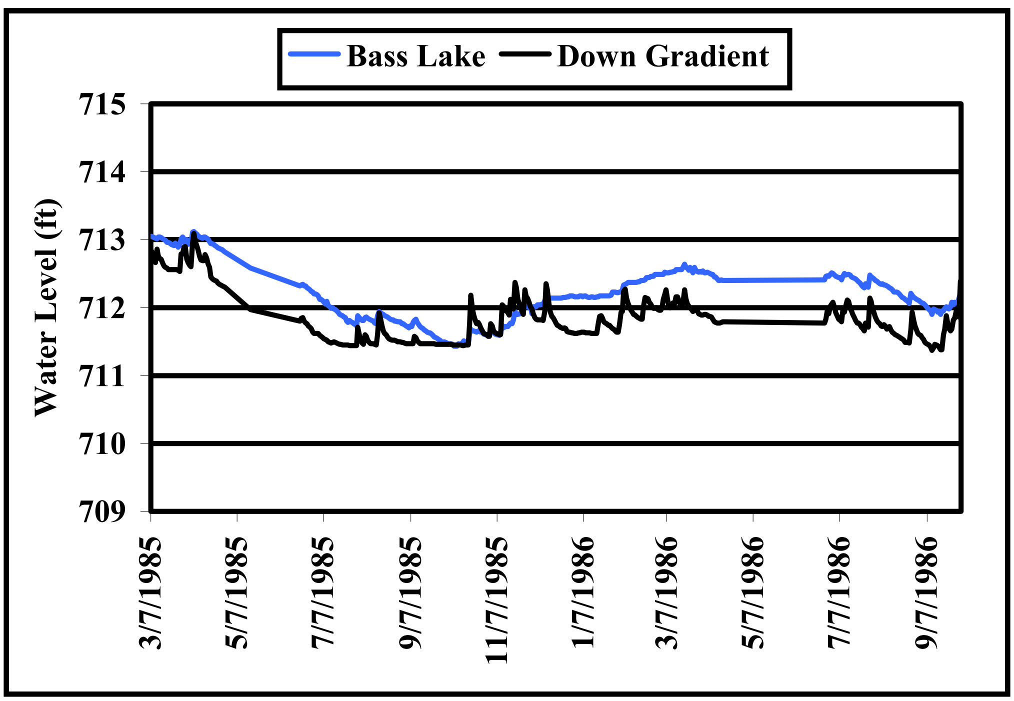

Figure 36. Water levels in a monitoring well located in the low-lying area west of Bass Lake in relation to the level of the lake surface (from records of IDNR-DOW). Note that the water levels in the lake are normally slightly higher than those on the adjacent plain although the hydraulic gradient sometimes reverses itself during periods of recharge.

Water Balance and Groundwater Modeling

The basic water balance equation for a lake can be written as follows:

$$\frac{\partial V}{\partial t} = (P - E)A + \Delta GW + \Delta SW \qquad (1)$$

where the term on the left hand side of the equation represents the rate of change of lake volume. The first term on the right hand side represents the net gain or loss of water due to precipitation and evaporation and the other two terms on the right hand side of the equation represent the net inflows or outflows of groundwater and surface water respectively. Since the watershed of Bass Lake is very small and most of the artificial ditches that surround the lake flow away from the lake (Beaty, 1990, p. 73), its water balance can be adequately modeled as a function of the net surface flux ($P - E$) and the net groundwater flux (ΔGW).

In order to evaluate what drives the long-term water balance of Bass Lake, precipitation and evaporation data were compiled from nearby weather stations for the 50-year period beginning in 1951 and ending in 2000. These data were used as transient surface fluxes in a hydrologic model of the region surrounding Bass Lake. Figure 37 shows the area that was modeled. This area was considered large enough to capture the water balance of the lake without it being adversely affected by artificial boundary conditions (e.g. no-flow boundaries) imposed along the periphery of the modeled area.

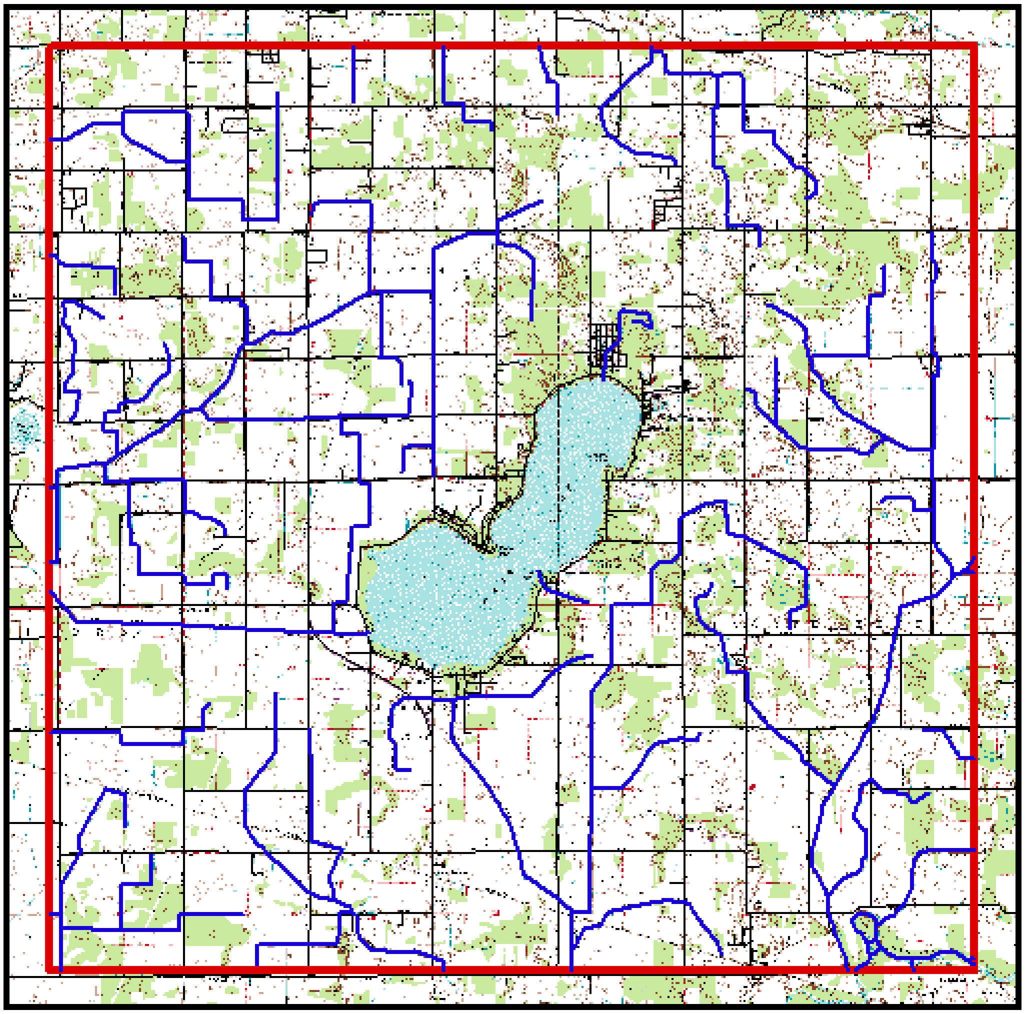

Figure 37. Area subjected to groundwater flow modeling. Thick blue lines indicate streams and ditches that were digitized and attributed for input to the groundwater flow model.

The general groundwater flow model used pertains to two-dimensional flow in a water table aquifer with spatially and temporally varying recharge. The governing equation is:

$$Kh\left[\frac{\partial^2 h}{\partial x^2}+\frac{\partial^2 h}{\partial y^2}\right]+R=S_y\frac{\partial h}{\partial t} \qquad (2)$$

where K is the average hydraulic conductivity of the water-table aquifer (~14 ft/d), h is the hydraulic head (water level) at location x,y in the study area at time t, R is the recharge rate of the water table aquifer at location x,y and at time t, and S_y is the specific yield of the aquifer material (~0.2 for sand). Equation 2 was solved numerically using an implicit finite-difference method (Mercer and Faust, 1981). The model area (Figure 37) was discretized into a grid containing 40,000 calculation cells, each cell being 30 m on a side. A cell size of 30 m by 30 m was chosen because that corresponds to the resolution of the digital elevation model (DEM) of the area obtained from the USGS. The streams and ditches shown on the figure were digitized and attributed, and then were incorporated into the groundwater model as fixed head boundary conditions. The bathymetry of the lake was incorporated into the DEM so it could be overlain onto the modeled water table surface to visualize the area of the lake resulting from different conditions. Initial water levels are required for transient groundwater modeling so they were estimated by solving a steady-state version of the groundwater flow model subject to constraints imposed by the average elevation of the streams and ditches, and the average level of Bass Lake. The steady state recharge rate was adjusted until it produced model heads that were similar to the average level of the DNR-DOW wells on the recharge and discharge sides of the lake.

In the transient model, spatially and temporally varying recharge was calculated using an analytical method developed by Kim et al. (1996). During storm periods the storage of water in the unsaturated zone increases by:

$$\Delta ST_t = \frac{P_t - E_t}{D\theta_s} \qquad (3)$$

where D is the thickness of the unsaturated zone at location x,y, ▶$_s$ is the saturated moisture content of the saturated porous medium (~0.35), and P_t and E_t are current values of precipitation and evaporation. Then following the storm, the rate of recharge is given by:

$$R_t = D\theta_s\left[ST_0 - ST_t\right] - E_t \qquad (4)$$

where ST_0 and ST_t are the initial (end of storm period) and current amounts of storage, respectively. At each non-storm time step, the current amount of storage is given by:

$$ST_t = \left(\left[St_0^{-c} + \frac{K}{E_t}\right]\exp\left[\frac{cE_t}{D\theta_s}t\right] - \frac{K}{E_t}\right)^{-1/c} \qquad (5)$$

where c is a soil dependent parameter approximately equal to 2.6 for sand (Kim et al., 1996). Of course, in the case of the lake itself, the recharge rate is equal to the rainfall (when it occurs) and the net groundwater flux (▶ *GW*) is determined by integrating the Darcy flux (resulting from the solution of Equation 2) along the periphery of the lake.

The coupled groundwater flow and water balance model was solved for the 50 years of record beginning in 1951 and ending in 2000. The results of the modeling exercise have been automated and can be viewed by opening the PowerPoint file named "Bass Topo.ppt" attached to this report and turning on the slide show. Refer to Appendix E for supporting explanatory materials prior to viewing the animated slide show.

The simulated water levels are compared to the measured water levels of the lake in Figure 38. Although the coupled water balance and groundwater model produced more extreme variations in lake level than actually occurred, when the modeled and measured lake levels are plotted on separate scales, the pattern of rises and drops is remarkably similar. There are several possible causes of the difference between the modeled and measured lake levels:

1. Since no pumping tests were conducted as part of this study, there is no way to validate the values of hydraulic conductivity and specific yield that were used in the model.
2. The simplified two-dimensional groundwater model did not account for any upward or downward movement of water from the deep aquifer beneath the lake.
3. Quantitative information about pumpage from the deep aquifer and the numerous domestic wells was insufficient for modeling purposes and therefore, excluded from the modeling exercise.
4. The evaporation data, which was collected from the Valparaiso Waterworks Station, are based on pan measurements that are known to be somewhat inaccurate.

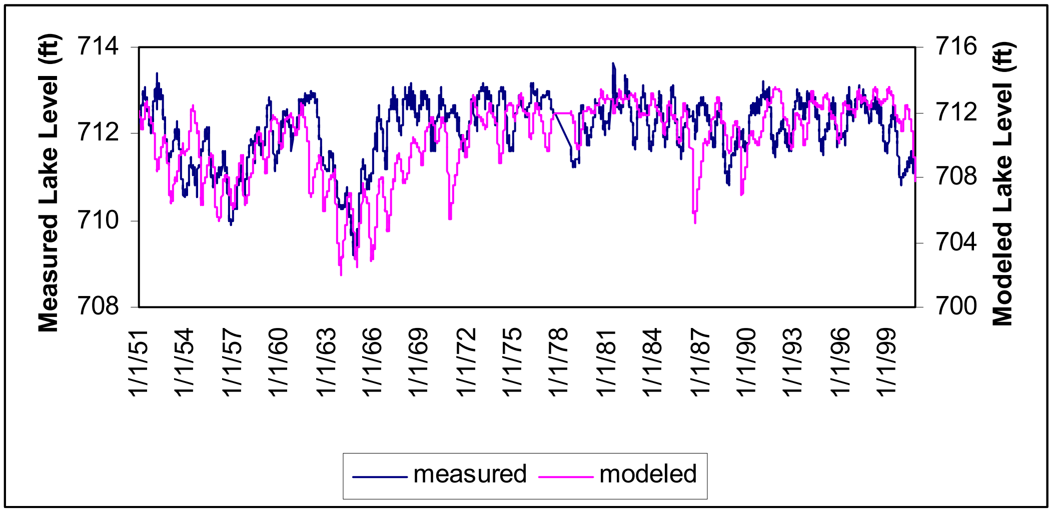

Figure 38. Comparison between measured and modeled levels of Bass Lake for the 50 year period from 1951 to 2000. Note that after adjusting for differences in the range of variation (different scales), the overall pattern of rising and falling lake level is quite similar.

Despite these shortcomings, the modeling results are useful from a diagnostic perspective. The balance between rainfall and evaporation, through its control over groundwater recharge and water table elevation, is the main cause of the fluctuations in level and area of Bass Lake. Indeed, by comparing Figures 38 and 39, it is evident that high lake levels occur when annual precipitation exceeds annual evaporation and low lake levels occur when annual evaporation exceeds annual precipitation. Also of note is the persistent negative balance between precipitation and evaporation that occurred from 1962 through 1964 resulting in the lowest lake levels recorded. The population along the lakefront was much less then than it is now so the big drop in the 1960's must have been by natural causes (precipitation deficit).

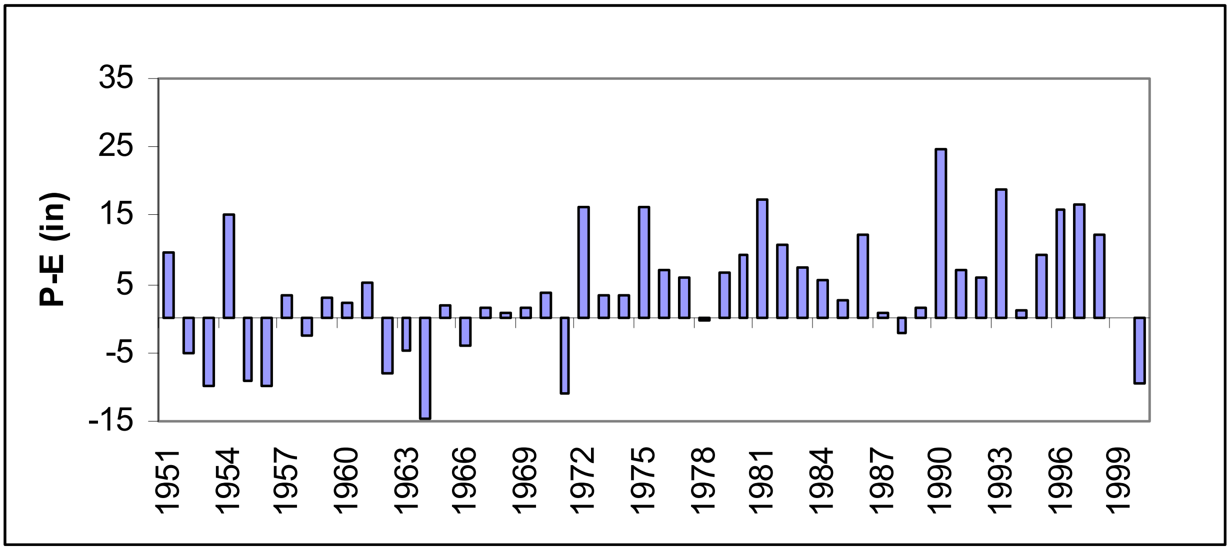

Figure 39. Difference between annual precipitation and evaporation during the period 1951 to 2000.

An analysis of the water balance calculations indicated that about 30% of the average inflow to the lake is from precipitation (rainfall and snow), and most of the remaining inflow (~47%) is from groundwater seepage. Unfortunately, average annual evaporation (as determined from data collected at Valparaiso) is only about 4% less than the average annual precipitation. These findings demonstrate that the water balance of the lake is extremely precarious. Increased pumping of the shallow aquifer is likely to exacerbate the lake level problem.

Based on the water balance model, it appears that if an attempt is made to keep the lake at its maximum level by sustained pumping of groundwater from the deep aquifer, then the average rate of pumping would be about 2 million gpd and the maximum rate would be more than 20 million gpd (this is based on a lake level drop of about 0.6 inches in a day). Note however, that these calculations are based on the questionable assumption that long term pumping will not cause water levels in the aquifer surrounding the lake to fall. Indeed, investigators from the IDNR-DOW have previously reported evidence that pumpage from the deep supply well causes a lowering of the water table adjacent to the lake (Beaty, 1990). Unfortunately, no sufficiently rigorous field experiments have been conducted to support or refute this hypothesis. Until the nature of the connection between the upper and lower aquifers is determined, augmentation of lake water by pumping at depth remains the most viable means of maintaining the level of the lake during prolonged periods of precipitation deficit.

LAKE MORPHOMETRY

Table 5 summarizes morphological characteristics of Bass Lake. Bass Lake is a two-lobed basin covering 1407 acres (569 ha). As described earlier, the lake bottom is spoon shaped with the deepest portion of the lake located in the northeast basin (Figure 40). The IDNR bathymetric map documents the lake's maximum depth as 30 feet (9 m); however, field measurements suggest the maximum depth is closer to 22-24 feet (approximately 7 m). The lake is very shallow possessing an average depth of 6 feet (1.9 m). The shoreline development ratio is a measure a lake's potential for development. It is calculated by dividing the shoreline length by the circumference of a circle that has the same area of the lake. As lake shape deviates from a perfect circle the shoreline development ratio increases in value and there is proportionally more shoreline per unit lake area. A perfectly circular lake with the same area as Bass Lake (1407 acres or 569 ha) would have a circumference of 27,751 feet (8458 m). Dividing Bass Lake's shoreline length by 27,751 feet yields a ratio of 1.6:1. This ratio is fairly low; Bass Lake consists of two relatively round basins, which lack significant embayment formation or channel development. Lakes with higher shoreline development ratios have higher potential for development, and this potential is often realized. Greater development around a lake has obvious impacts on the health of the lake system.

Table 5. Morphological characteristics of Bass Lake.

Bass Lake	
Surface Area	1407 acres (569 ha)
Volume	8557acre-ft (10,558,758 m3)
Maximum Depth	30 ft (9 m)
Mean Depth	6 ft (1.9m)
Shoreline Length	43,863 ft (13,369 m)
Shoreline Development Ratio	1.6:1

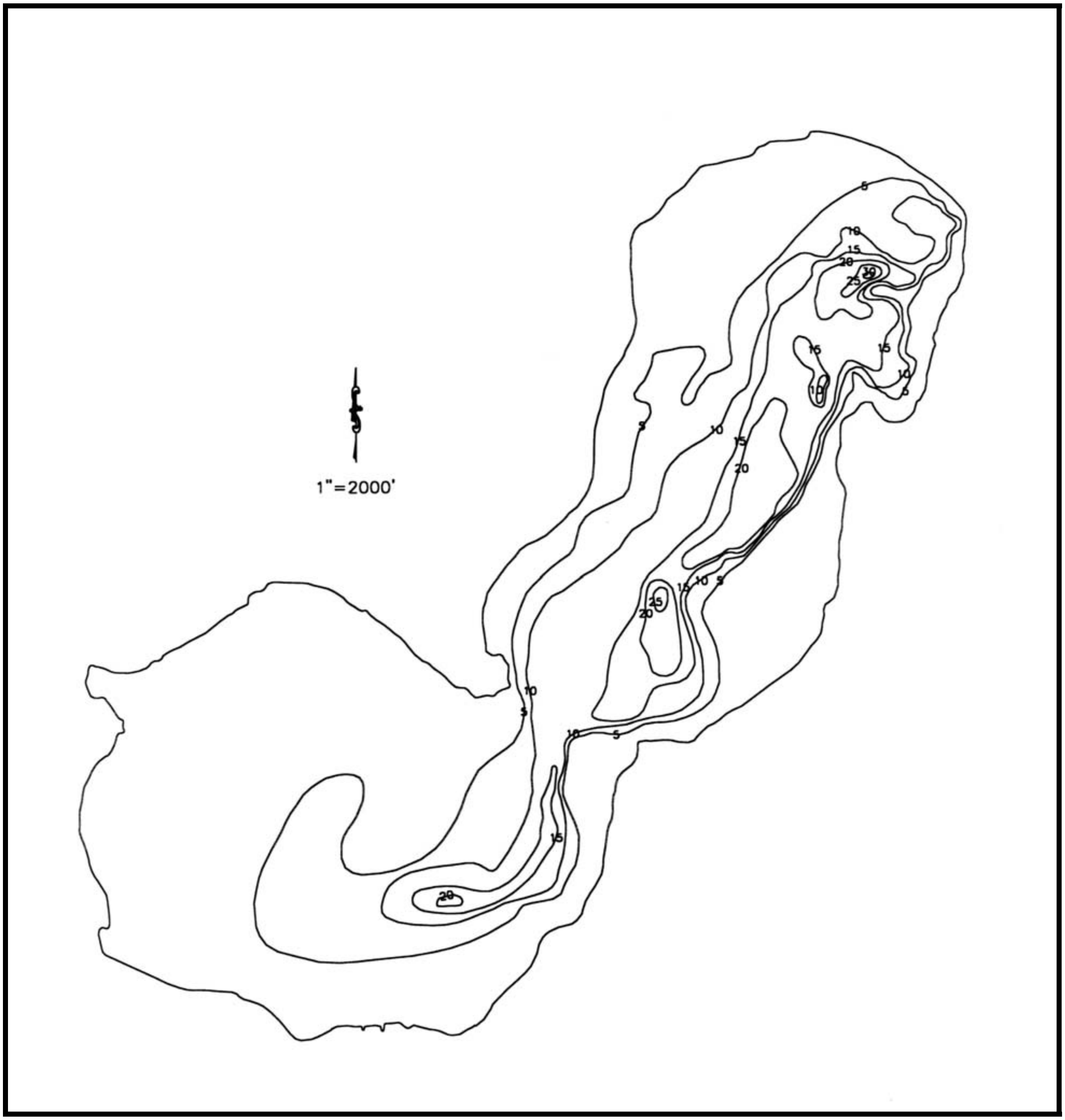

Figure 40. Bathymetric map of Bass Lake. Source of Base Map: IDNR Division of Water Bathymetric Map of Bass Lake (1988).

Depth-area and depth-volume curves were developed from the IDNR bathymetric map for Bass Lake (Figures 41-42). Bass Lake possesses a large shallow area with over 75 percent of the lake being less than 10 feet (3.1 m) deep. Volume increases uniformly with depth in Bass Lake until approximately 12 feet (3.7 m) where there is a sharp increase in depth per unit volume. The sharp increase in depth per unit volume suggests that very little of Bass Lake's volume is contained in the lake's deeper water.

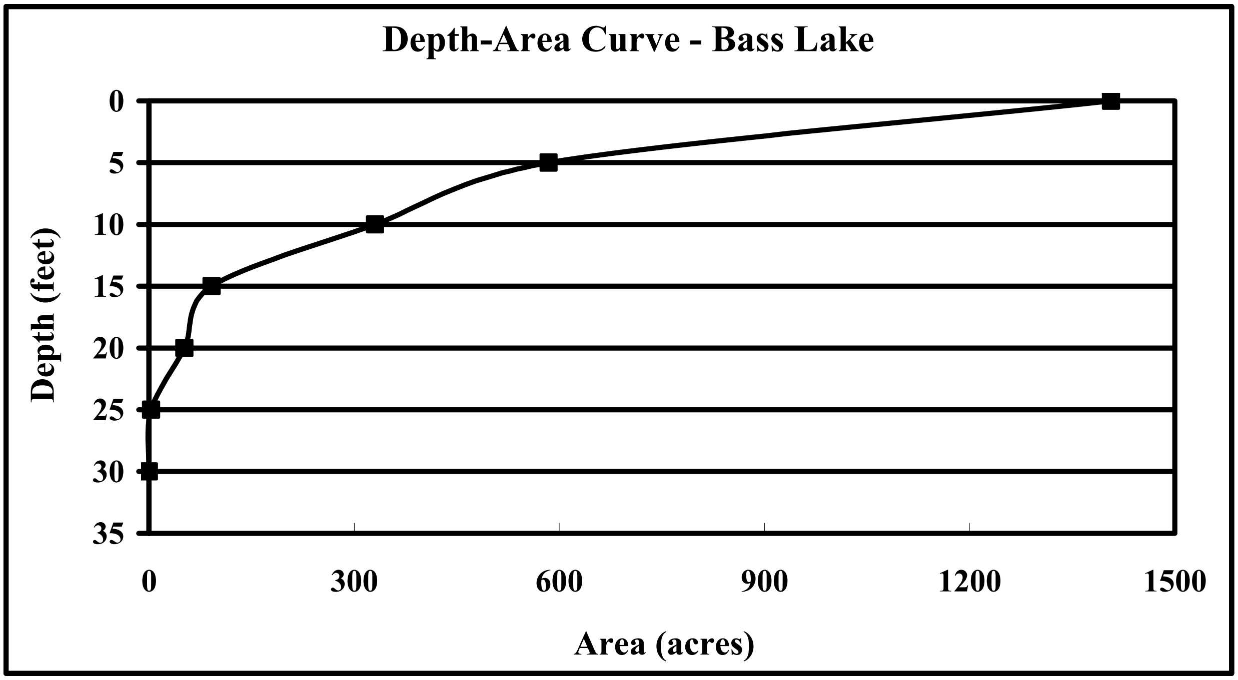

Figure 41. Depth-area curve for Bass Lake

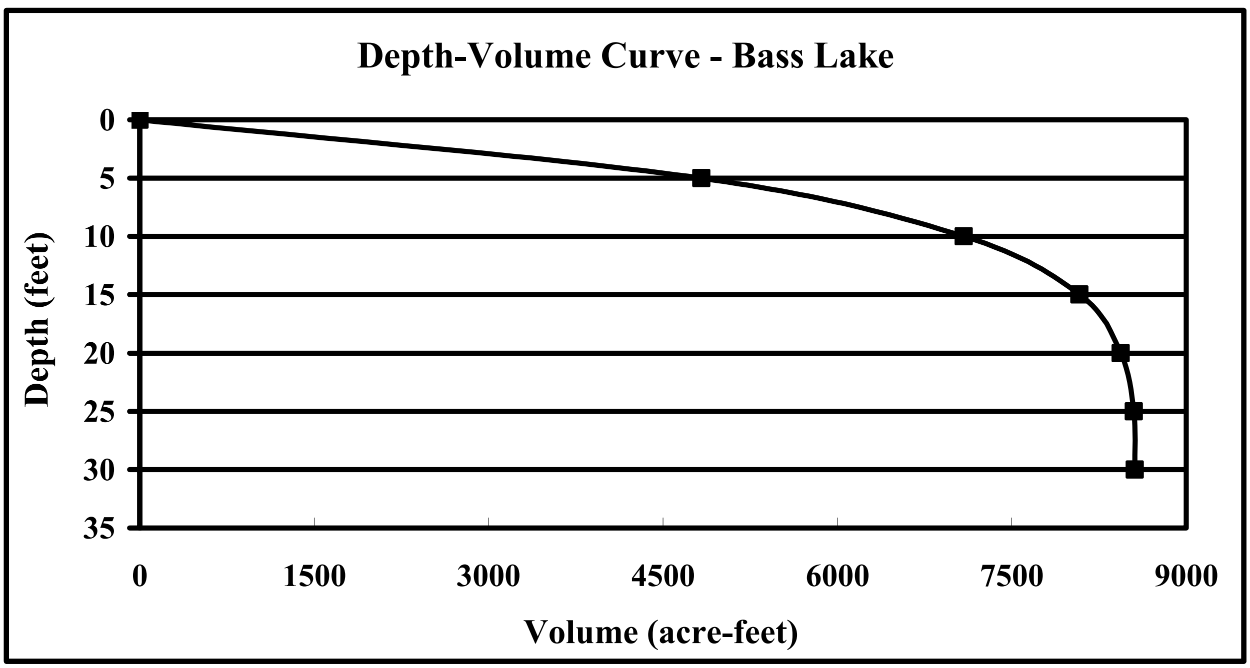

Figure 42. Depth-volume curve for Bass Lake.

These curves are extremely useful in illustrating important relationships between depth, volume, and area. For example, if a rooted plant can grow in water up to ten feet deep, the potential habitat for this plant is approximately 1070 acres (433 ha) in Bass Lake. This suggests that rooted plants are capable of growing in 76% of Bass Lake. Results from the macrophyte survey indicate that rooted plants cover less than 10% of the lake's surface area suggesting that other factors may be limiting rooted plant growth in the lake. (See the Macrophyte section for more details.) The lake's physical morphometry impacts the fish community as well. Predator fish species often require deep holes for refuge. The presence and size (volume) of such holes determines the number of predator fish species that the lake has the ability to support. (More detailed explanations of how the lake's morphometry impacts the lake's biota and water chemistry are provided in the following sections.)

WATER QUALITY

Introduction

Before reviewing the results of the historical water quality assessments of Bass Lake, it may be useful to explore the way limnologists evaluate the ecological health of lakes. In evaluating a lake, a limnologist will measure a variety of water quality parameters. These include measurements of nutrient and dissolved oxygen concentrations, water clarity, and light penetration through the water column. Limnologists often evaluate lakes based on these measurements alone or incorporate these measurements into an index to measure the parameters collectively. These parameters and indices indicate whether the lake water is clear or turbid; whether the lake supports, or can support, diverse, native flora and fauna communities; and whether the lake can provide desired recreational opportunities for lake residents. The following paragraphs describe the typical parameters measured during lake assessments and how these parameters are incorporated in various lake health indices.

Water Quality Parameters

Nutrients

Limnologists measure nutrients to predict the amount of algae growth and/or rooted plant (macrophyte) growth that is possible in a lake. Algae and rooted plants are a natural and necessary part of a lake ecosystem. Both will always occur in a healthy lake. Complete elimination of algae and/or rooted plants is neither desirable nor even possible and should, therefore, never be lake residents' goal in managing their lake. Algae and rooted plant growth can, however, reach nuisance levels and interfere with the aesthetic and recreational uses of a lake. Limnologists commonly measure nutrient concentrations in lake evaluations to determine the potential for such nuisance growth.

Like terrestrial plants, algae and rooted aquatic plants rely primarily on phosphorus and nitrogen for growth. Aquatic plants receive these nutrients from fertilizers, human and animal waste, atmospheric deposition in rainwater, and yard waste or other organic material that reaches the lake. Nitrogen can also diffuse from the air into the lake. This nitrogen is then "fixed" by certain algae species into a usable, "edible" form of nitrogen. Because of this readily available source of nitrogen (the air), phosphorus is usually the "limiting nutrient" in aquatic ecosystem. This means that it is actually the amount of phosphorus that controls plant growth in a lake. While this is not the case in all lakes, evidence from historical water quality sampling suggests that phosphorus is indeed the limiting nutrient in Bass Lake.

Phosphorus and nitrogen have several forms in lake water. The two common phosphorus forms are **soluble reactive phosphorus (SRP)** and **total phosphorus (TP)**. SRP is the dissolved form of phosphorus. It is the form that is "usable" by algae. Algae cannot directly digest and use particulate phosphorus. Total phosphorus is a measure of both dissolved and particulate forms of phosphorus. The most commonly measured nitrogen forms are **nitrate-nitrogen (NO_3)**, **ammonium-nitrogen (NH_4^+)**, and **total Kjeldahl nitrogen (TKN)**. Nitrate is a dissolved form of nitrogen that is commonly found in the upper layers of a lake where oxygen is readily available. In contrast, ammonium-nitrogen is generally found in the lower layers of a lake where oxygen is lacking. Ammonium is a byproduct of decomposition generated by bacteria as they decompose organic material that has sunk to the bottom of a lake. Like SRP, ammonium is a dissolved form of nitrogen and the one utilized by algae for growth. The TKN measurement parallels the TP measurement to some extent. TKN is a measure of the **total organic nitrogen** (particulate) and ammonium-nitrogen in the water sample.

While the United States Environmental Protection Agency (EPA) has established some nutrient standards for drinking water safety, it has not established similar nutrient standards for protecting the biological integrity of a lake. (The EPA, in conjunction with the States, is currently working on developing these standards.) Despite this, limnologists have determined the existence of certain thresholds for nutrients above which changes in the lake's biological integrity can be expected. For example, 0.03 mg/L (0.03 ppm – parts per million or 30 ppb – parts per billion) is the generally accepted threshold for total phosphorus. Concentrations above this level can promote nuisance algae blooms. Levels of inorganic nitrogen that exceed 0.3 mg/L may also promote algae blooms. In addition, high levels of nutrients, particularly nitrate and ammonium, can be lethal to fish. The nitrate LC_{50} is 5 mg/L for logperch, 40 mg/L for carp, and 100 mg/L for white sucker. (Determined by performing a bioassay in the laboratory, the LC_{50} is the concentration of the pollutant being tested, in this case nitrogen, at which 50% of the test population died in the bioassay.) Lastly, the Indiana Administrative Code (IAC) requires that all waters of the state have a nitrate concentration of less than 10 mg/L, which is the drinking water standard for the state.

Chlorophyll a

While nutrient parameters suggest the *potential* for algae and rooted plant growth, **chlorophyll *a*** measurements are used to indicate the actual presence of algae in the water. Chlorophyll *a* is one of the pigments found in plant material. It plays a role in the plant's ability to photosynthesize. Because algae are plants, they, too, contain chlorophyll *a*. Like the nutrient parameters, no standard for chlorophyll *a* exists. In general, chlorophyll a concentrations below 2 μg/L are considered low, while those exceeding 10 μg/L are considered high and indicative of poorer water quality.

Water Clarity

Because it affects both the inhabitants in the lake and those around the lake (homeowners), limnologist's commonly measure water clarity in lake assessments. Sedimentation (the input of dirt) to a lake decreases the lake's life span and creates deltas and sand bars that could limit recreational uses of the lake. On shallower lakes such as Bass Lake, lake bottom sediments can be resuspended through boating activity or wave action, inhibiting water clarity. Suspended sediment impacts a lake's biota. Heavy silt loads can deteriorate fish spawning grounds and alter fish community composition by shifting dominance to more tolerant species. Sediment, algae, and other materials suspended in a lake also ruin the lake's aesthetic value. Few lake residents or visitors are attracted to murky water and silt covered lake bottoms.

Limnologists use a variety of methods to measure lake water clarity. **Secchi disk transparency** is the most common measure of water clarity. Secchi disk transparency is measured in the field by lowering a 20-cm diameter disk divided into alternating black and white quadrants into the lake until it can no longer be seen. The biologist performing the measurement records this depth. The disk is then raised until the biologist observes the disk again. The biologist records this second depth. The Secchi disk transparency depth is the average of these measurements. In general, lakes possessing Secchi disk transparency depths greater than 15 feet (4.5 m) have outstanding clarity. Lakes with Secchi disk transparency depths less than 5 feet (1.5 m) possess poor water clarity (ISBH, 1975; Carlson, 1977).

The ability of light to penetrate through the water column is another way to evaluate the lake's water clarity. Limnologists will measure **light transmission at 3 feet** (0.9 m) below the water surface and compare it to the light reaching the lake surface to obtain the percentage of the total light transmission at 3 feet (0.9 m). In clearer lakes, light travels unimpeded through the water column and a large percentage (> 70%) of it reaches 3 feet (0.9 m) into the lake's water column. In lakes with poorer clarity, a lower percentage of light reaches 3 feet (0.9 m) into the lake's water column as suspended particles in the light absorb or reflect the light before it reaches the 3-foot depth.

Finally, limnologists often measure the depth at which light transmission equals 1% of the light reaching the lake's surface. This depth, the 1% light level, marks the lower limit of the lake's photic zone. The photic zone is that portion of the lake that has sufficient light to support plant life. Lakes with large photic zones (deep 1% light levels) have the *potential* to support more algae than lakes with limited photic zones.

Dissolved oxygen

Dissolved oxygen (D.O.) is a measure of how much oxygen is in the lake water. Just like their terrestrial counterparts, lake fauna require oxygen to breath and sustain life. Oxygen is also utilized in decomposition processes that occur in the lake. Much of the oxygen in the water column originates from the air above the lake. Plants (rooted and algae) also produce oxygen as a byproduct of photosynthesis. Occasionally, excessive algae growth can over-saturate lake water with oxygen.

The amount of D.O. in a lake can affect a variety of chemical reactions in the water. In many lakes, particularly lakes that stratify (become layered due to differences in temperature among the layers), decomposition processes use up available oxygen leading to a lack of oxygen in the lake's lower water layer. Without the presence of oxygen, phosphorus bound to the lake sediments may be released into the water column. The phosphorus is released as SRP, the form that is readily used by algae. The lack of oxygen also prevents the conversion of ammonium to nitrate. Thus, more of the usable form of nitrogen is available for algae growth.

As with other lake parameters, no oxygen criteria exist. Fish need at least 3 to 5 mg/L of D.O. Coldwater fishes including trout and cisco have greater oxygen requirements than warmwater fishes such as bluegill and bass. In addition, D.O. concentrations above 1 mg/L are necessary to prevent the release of phosphorus from the bottom sediments.

Trophic States

When considering a lake's water quality, lake residents are often more familiar with the terms *oligotrophic, mesotrophic, eutophic,* and *hypereutrophic* than many of the water quality parameters measured during lake evaluations. These terms describe a lake's trophic state (i.e. how productive the lake is, how much plant and algae growth is present, etc.). The terms categorize lakes with respect to productivity (amount of rooted plant and algae growth) and water quality. These terms are qualitative in nature, broadly defined, and lack rigid dividing lines separating individual categories. The following paragraphs briefly describe each of the terms.

Oligotrophic lakes are those lakes with the highest water quality. These lakes possess low nutrient (phosphorus and nitrogen) concentrations and, as a consequence, do not typically support algae blooms or extensive rooted plant populations. Oligotrophic lakes have clear water transparency. They support less tolerant organisms such as coldwater fish which have higher oxygen requirements than warmwater fish.

Mesotrophic lakes are characterized by intermediate nutrient concentrations and intermediate productivity. These lakes can support algae but the severe blooms associated with eutrophic and hypereutrophic lakes are not common in mesotrophic lakes. Similarly, mesotrophic lakes support some rooted plants but not at nuisance levels.

Eutrophic lakes are productive lakes. They possess high nutrient concentrations and are able to support algae blooms and extensive rooted plant populations. Eutrophic lakes often exhibit a lack of oxygen in the bottom waters during summer stratification. This lack of oxygen limits the habitat potential of the lake.

Hypereutrophic lakes are highly productive lakes. These lakes possess very high concentrations of nutrients and support nuisance populations of rooted plants and have severe algae blooms. Algal blooms are so severe that the term "pea-soup" is often used to characterize hypereutrophic lakes. Transparency is poor in these lakes. Oxygen levels are low in hypereutrophic lakes; fish kills associated with low oxygen are common in hypereutrophic lakes.

Trophic State Indices

Although the definitions listed above are qualitative, some limnologists have developed numerical criteria for placing lakes in one of the four trophic states. The primary way limnologists do this is through the use of a trophic state index. A trophic state index (TSI) evaluates several water quality parameters by condensing the parameters into a single number. The single number is then compared to numerical ranges for the four trophic states. Two of the more common TSI's used to assess Indiana lakes are the Indiana TSI (ITSI) and the Carlson TSI.

Indiana TSI

Harold Bon Homme and the Indiana Stream Pollution Control Board developed the first Indiana TSI (or Eutrophication Index (EI)). The Indiana Department of Environmental Management later modified the index, creating the TSI in use today. The original ITSI (EI) differed slightly from the one in use today. Today's ITSI uses ten different water quality parameters to calculate a score. The following table shows the point values for each parameter.

Table 6. The Indiana Trophic State Index

Parameter and Range		Eutrophy Points
I.	Total Phosphorus (ppm)	
	A. At least 0.03	1
	B. 0.04 to 0.05	2
	C. 0.06 to 0.19	3
	D. 0.2 to 0.99	4
	E. 1.0 or more	5
II.	Soluble Phosphorus (ppm)	
	A. At least 0.03	1
	B. 0.04 to 0.05	2
	C. 0.06 to 0.19	3
	D. 0.2 to 0.99	4
	E. 1.0 or more	5
III.	Organic Nitrogen (ppm)	
	A. At least 0.5	1
	B. 0.6 to 0.8	2
	C. 0.9 to 1.9	3
	D. 2.0 or more	4
IV.	Nitrate (ppm)	
	A. At least 0.3	1
	B. 0.4 to 0.8	2
	C. 0.9 to 1.9	3
	D. 2.0 or more	4
V.	Ammonia (ppm)	
	A. At least 0.3	1
	B. 0.4 to 0.5	2
	C. 0.6 to 0.9	3
	D. 1.0 or more	4
VI.	Dissolved Oxygen: Percent Saturation at 5 feet from surface	
	A. 114% or less	0
	B. 115% to 119%	1
	C. 120% to 129%	2
	D. 130% to 149%	3
	E. 150% or more	4

VII. Dissolved Oxygen:
Percent of measured water column with at least 0.1 ppm dissolved oxygen

A.	28% or less	4
B.	29% to 49%	3
C.	50% to 65%	2
D.	66% to 75%	1
E.	76% 100%	0

VIII. Light Penetration (Secchi Disk)

A.	Five feet or under	6

IX. Light Transmission (Photocell): Percent of light transmission at a depth of 3 feet

A.	0 to 30%	4
B.	31% to 50%	3
C.	51% to 70%	2
D.	71% and up	0

X. Total Plankton per liter of water sampled from a single vertical tow between the 1% light level and the surface:

A.	less than 3,000 organisms/L	0
B.	3,000 - 6,000 organisms/L	1
C.	6,001 - 16,000 organisms/L	2
D.	16,001 - 26,000 organisms/L	3
E.	26,001 - 36,000 organisms/L	4
F.	36,001 - 60,000 organisms/L	5
G.	60,001 - 95,000 organisms/L	10
H.	95,001 - 150,000 organisms/L	15
I.	150,001 - 500,000 organisms/L	20
J.	greater than 500,000 organisms/L	25
K.	Blue-Green Dominance: additional points	10

Values for each water quality parameter are totaled to obtain an ITSI score. Based on this score, lakes are then placed into one of five categories (Table 7). Four of these categories correspond to the qualitative lake productivity categories. The fifth category, dystrophic, is for lakes that possess high nutrient concentrations but have limited rooted plant and algal productivity (IDEM, 2000). In these lakes, plant productivity is controlled by a factor other than nutrient availability.

Table 7. Indiana Trophic State Index Score related to Water Quality

TSI score	Water Quality (Productivity)
0-15	Oligotrophic
16-31	Mesotrophic
32-46	Eutrophic
47-75	Hypereutrophic
*	Dystrophic

* See explanation above.

Carlson Trophic State Index

Another commonly used TSI is the Carlson TSI. Carlson (1977) examined several Wisconsin lakes to understand the relationship between three common water quality parameters, Secchi disk transparency, phosphorus concentration, and chlorophyll *a* concentration, and lake productivity (or trophic state). From this study, he derived three equations that form the basis of the Carlson TSI:

$$TSI = 10\ (6 - \log_2 SD)$$

$$TSI = 10\ (6 - \log_2 7.7/\text{chlorophyll } a^{\ 0.68})$$

$$TSI = 10\ (6 - \log_2 48/TP)$$

where SD stands for Secchi disk transparency and TP stands for total phosphorus. As the equations indicate, a TSI score can be calculated using only one water quality parameter. That TSI score can then be used to predict the values of the other two parameters. For example, if the Secchi disk transparency of a lake is known, the lake's total phosphorus and chlorophyll *a* concentrations can be predicted using Carlson's equations.

Although Carlson may not have intended to correlate qualitative water quality categories to the TSI scores from his index (Cooke et al., 1993), a correlation has been developed. Figure 43 relates Carlson's TSI score to lake trophic state.

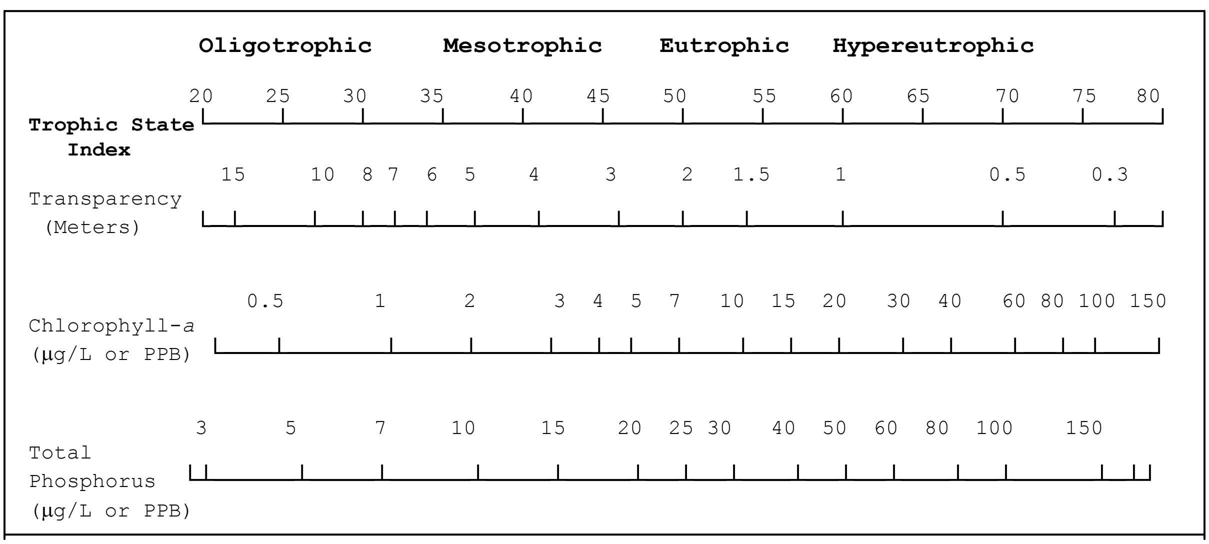

Figure 43. Carlson's Trophic State Index

The Carlson TSI has been applied to lakes across the Midwest. Like the Indiana TSI, it does have its limitations and should be used with caution under certain lake conditions. The Carlson TSI is most applicable in lakes that are similar to those used to develop the TSI. In general, it should be applied to lakes that have low non-algal turbidity and lack extensive rooted plant populations (Cooke et al., 1993).

Bass Lake Historical Results

Several governmental agencies including the United States Environmental Protection Agency, the Indiana Department of Natural Resources, Division of Fish and Wildlife, the Indiana State Board of Health, Stream Pollution Control Board, and the Indiana Clean Lakes Program have conducted water quality studies on Bass Lake since the early 1970's. A citizen volunteer collected Secchi disk data on Bass Lake in 1989. The following paragraphs summarize the results of these studies.

Figure 44 presents historical temperature profiles for Bass Lake for selected years. Many northern Indiana lakes stratify during the summer months establishing three somewhat overlapping zones: the well mixed upper layer called *epilimnion*, the lower layer near the lake's bottom called the *hypolimnion* and a separating layer where the rate of temperature change with depth is greatest called the *metalimnion*. In contrast to most northern Indiana lakes, Bass Lake does not exhibit this stratified structure in most years and was very weakly stratified in 1995 and 1999 (Figure 44).

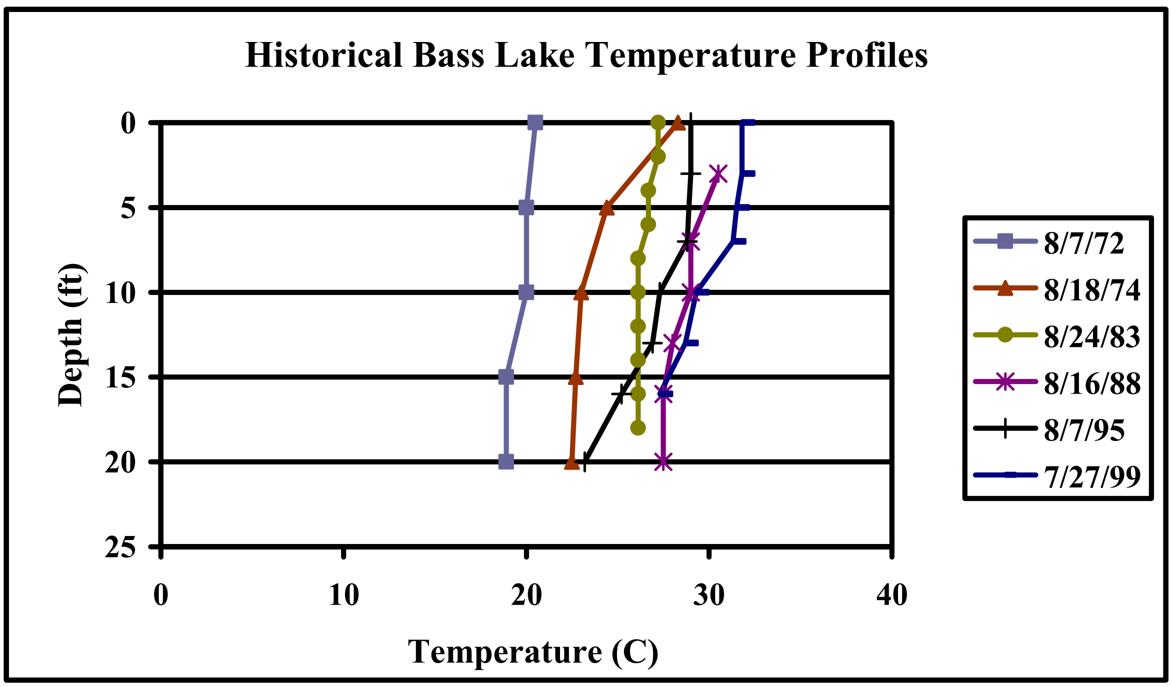

Figure 44. Historical temperature profiles for Bass Lake.

Figure 45 presents historical dissolved oxygen profiles for the same years. In the 1970's and 1980's, Bass Lake's water column appears to be at least sufficiently oxygenated; dissolved oxygen concentrations are at or above 4 mg/L throughout the water column during that time period. The 1995 and 1999 Clean Lakes Program assessment indicate that dissolved oxygen disappears from the water column at approximately 16 feet (4.8 m) below the water surface, leaving the lower portion of the water column anoxic.

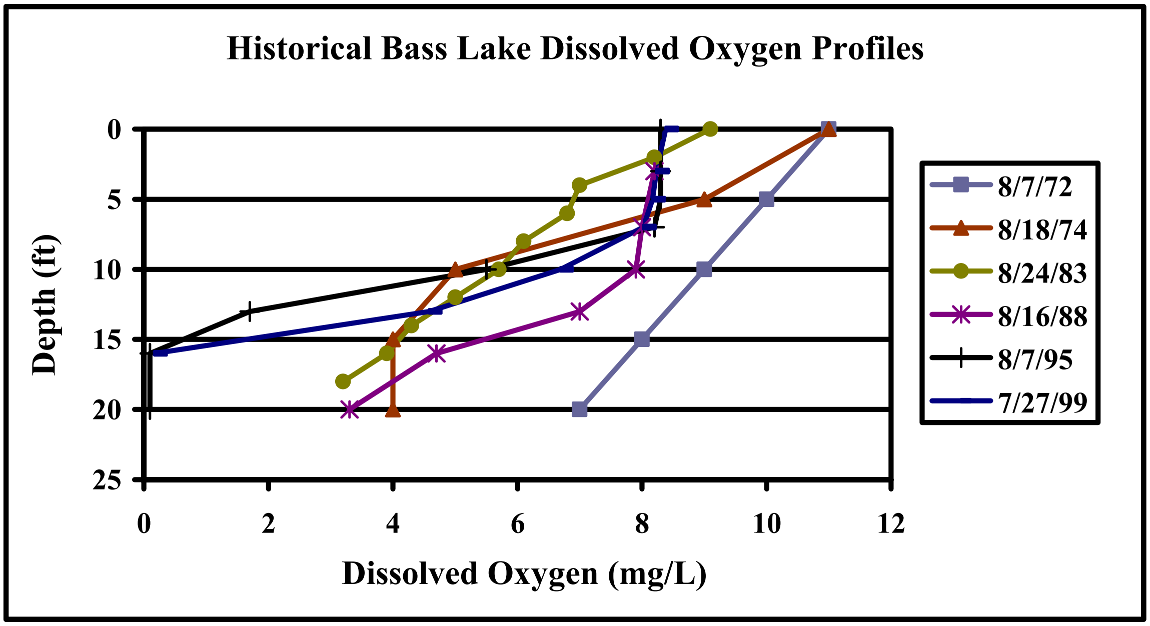

Figure 45. Historical dissolved oxygen profiles for Bass Lake.

Figure 46 presents the historical Secchi disk transparency measurements made in Bass Lake from 1972 to 1999. As the figure shows, Secchi disk measurements are highly variable. Typically, seasonal changes that affect watershed runoff and algal communities create most of the variability observed in Secchi disk measurements on lakes. Due to the shallowness of Bass Lake, the day of the week on which the measurement was taken can impact the Secchi disk depth. For example, in the summer when boating activity is high, a Secchi disk depth recorded on a Monday following a warm, sunny weekend will likely be less than a Secchi disk depth recorded on Thursday of the same week. Heavy weekend boating activity on Bass Lake can impair the lake's water clarity well into the early part of the following week (Bob Robertson, personal communication).

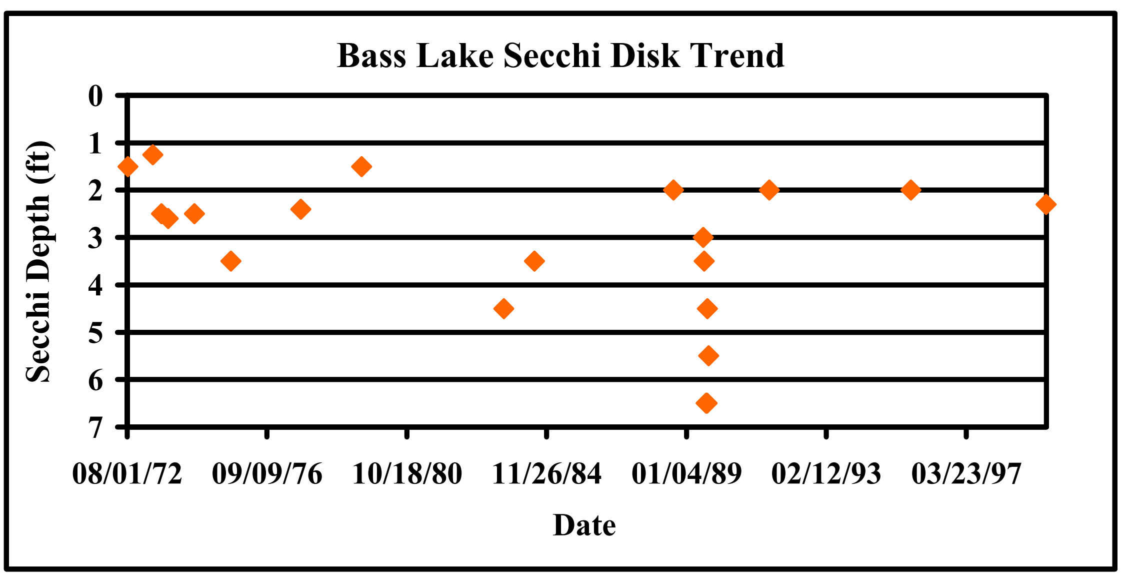

Figure 46. Secchi disk transparency trend.

In general, Bass Lake exhibits poor water clarity with Secchi disk depths ranging from 1 to 4 feet (0.3 to 0.9 m). Figure 46 does not suggest a trend toward increasing or decreasing water clarity over time. A slight improvement in water clarity occurred in the 1980's. Scores recorded in the 1980's ranged from 2.0 to 6.5 feet (0.6-2 m). In fact, of the eight times the measured Secchi disk depth in Bass Lake exceeded 3 feet (0.9 m), seven of those occurred during the 1980's. In the 1990's, water clarity appears to decrease with Secchi disk depths returning to the range documented in the 1970's.

Because phosphorus is likely the nutrient responsible for controlling algae growth, examining the historical total phosphorus concentrations in Bass Lake will assist in determining whether the potential for nuisance algae growth is increasing or decreasing. Figure 47 summarizes the historical total phosphorus measurements in the Bass Lake from 1972 to 1999. Except for possibly the August 7, 1972 concentration, the concentrations in Figure 47 are water column averages. The August 7, 1972 concentration (0.02 mg/L) may be an epilimnetic concentration; it is unclear from the IDNR Fisheries Report in which this concentration is reported whether it is a surface concentration or water column average concentration. To make the graph easier to read, it excludes one outlier, a 0.7 mg/L concentration recorded on September 6, 1977 by the Indiana State Board of Health.

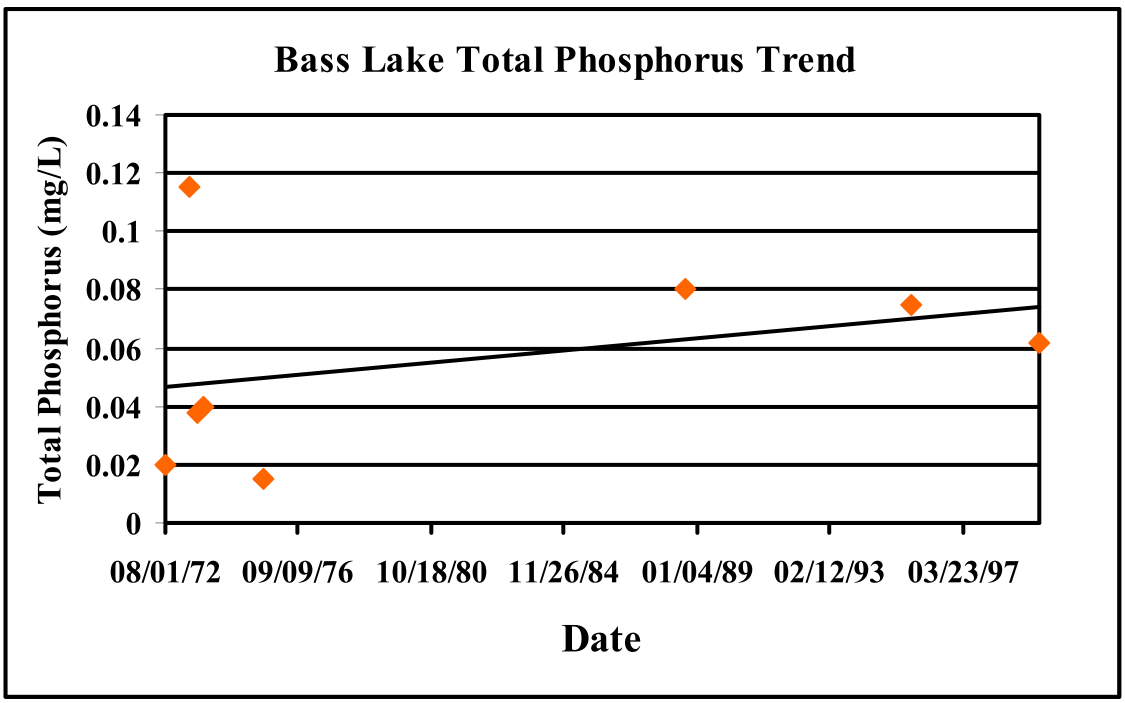

Figure 47. Total phosphorus trend for Bass Lake.

Bass Lake exhibits a wide range of historical total phosphorus concentrations. Excluding the outlier mentioned above, half of the recorded concentrations are below or just over the 0.03 mg/L threshold at which nuisance algal blooms are possible. The other half exceed this threshold by a factor of two or three. Although Bass Lake possessed the highest historical concentrations on May 3, 1973 and September 6, 1977, the lake possessed lower total phosphorus concentrations in the 1970's compared to the concentrations recorded in the 1980's and 1990's. From this, it appears that the concentration of total phosphorus in Bass Lake is increasing over time.

The 1975 and 1977 studies conducted by the Indiana State Board of Health and the 1988, 1995, and 1999 studies conducted by the Indiana Clean Lakes Program assessed the lake using either the Indiana Trophic State Index or its predecessor, the BonHomme Eutrophication Index. As explained earlier in this section, a TSI (or the EI) is a method for condensing a variety of water quality parameters into a single score that roughly establishes a lake's productivity level or trophic state. Tables 8 and 9 present the Indiana TSI calculations for the most recent evaluations on Bass Lake (1995 and 1999). Appendix F contains the BonHomme Eutrophication Index calculations for the Bass Lake assessments conduction in 1975, 1977, and 1988. Table 10 summarizes the Indiana TSI and BonHomme EI scores for Bass Lake from 1975 to 1999.

Table 8. Results of the 1995 Lake Water Quality Assessment of Bass Lake.

Parameter	**Epilimnetic Sample**	**Hypolimnetic Sample**	**Indiana TSI Points (based on mean values)**
pH	8.65	7.35	-
Alkalinity (mg/L)	72	98	-
Conductivity (umhos)	228	288	-
Secchi Depth Transparency ft)	2.0		6
Light Transmission @ 3 ft.	28%		4
1% Light Level (ft)	9		-
Total Phosphorous (mg/L)	0.042	0.106	3
Soluble Reactive Phosphorous (mg/L)	0.012	0.018	0
Nitrate-Nitrogen (mg/L)	0.022	0.022	0
Ammonia-Nitrogen (mg/L)	0.018	0.559	0
Organic Nitrogen (mg/L)	1.339	2.928	4
Oxygen Saturation @ 5 ft.	108		0
% Water Column Oxic	86		0
Plankton Density (#/L)	22840		3
Blue-Green Dominance	No		0
Chlorophyll *a* (µg/L)	6.06		-
TSI Score			**20**

Table 9. Results of the 1999 Lake Water Quality Assessment of Bass Lake.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	8.4	7.3	-
Alkalinity (mg/L)	75	80	-
Conductivity (umhos)	249	246	-
Secchi Depth Transparency (ft)	2.3		6
Light Transmission @ 3 ft.	21%		4
1% Light Level (ft)	8		-
Total Phosphorous (mg/L)	0.053	0.071	3
Soluble Reactive Phosphorous (mg/L)	0.015	0.015	0
Nitrate-Nitrogen (mg/L)	0.022	0.022	0
Ammonia-Nitrogen (mg/L)	0.018	0.018	0
Organic Nitrogen (mg/L)	0.722	0.93	2
Oxygen Saturation @ 5 ft.	107.3%		0
% Water Column Oxic	73		1
Plankton Density (#/L)	3042		1
Blue-Green Dominance	Yes		10
Chlorophyll *a* (μg/L)	21.36		-
TSI Score			**27**

Table 10. Summary of historical Indiana TSI scores for Bass Lake, 1975-1999.

Year	TSI Score
1975	36
1977	39
1988	42
1995	20
1999	27

The trend in the TSI scores contrasts with that observed with the total phosphorus concentrations in Bass Lake. The scores from 1975 to 1988 are higher than those recorded in 1995 and 1999 suggesting an improvement in water quality over the years. From 1975 to 1988 scores ranged from 36 to 42 placing Bass Lake in the eutrophic category. The 1995 and 1999 scores were 20 and 27, respectively, which fall in the mesotrophic range.

Some consistencies among the TSI evaluations exist. For example, each year the lake received 6 points in the assessment for poor Secchi disk depths. High TSI scores correspond to poor water quality. In four of the five years assessed, the lake received the maximum number of points (4) for low light transmission at three feet (0.9 m) below the water surface. Only in 1975 did light transmission at 3 feet (0.9 m) exceed 30%. With the exception of the 1975 assessment, the lake received a consistently high score (3 or 4) for total phosphorus. Similarly, the lake possessed high organic nitrogen concentrations and received scores of 3 or 4 for these concentrations in each year except 1999.

The algal parameters appear to have exerted the greatest influence in determining the overall TSI score and, thus, separating the 1975 and 1977 scores from the 1995 and 1999 scores. Bass Lake received 20 and 23 points for algae (density and blue green dominance) in 1975 and 1979, respectively, compared to only 3 and 11 in 1995 and 1999 respectively. (Because algae data is missing from the 1988 data sheet, it is impossible to determine the exact amount of points algal parameters contribute to the total TSI score in 1988.)

Whether the decrease in algal parameters points observed in the more recent evaluations compared to earlier evaluations truly reflects a significant decrease in algal abundance in Bass Lake and therefore an improvement of water quality is unclear. The BonHomme EI utilizes slightly different collection and scoring methods than those currently in use. It is possible that if the Clean Lakes Program conducted the 1995 and 1999 lake evaluations using the same collection and scoring methods used during the previous (1975, 1977, and 1988) lake evaluations, the difference in overall TSI/EI scores may not be as great. Unfortunately, this hypothesis cannot be tested.

Bass Lake 2001 Sampling

Methods

The water sampling and analytical methods used for the Bass Lake 2001 sampling were consistent with those used in IDEM's Indiana Clean Lakes Program (CLP) and IDNR's Lake and River Enhancement Program. J.F. New & Associates (New) collected water samples for various parameters on August 10, 2001 from the surface waters (***epilimnion***) and from the bottom waters (***hypolimnion***) at the deepest point of the lake. These parameters include pH, alkalinity, conductivity, total suspended solids, total phosphorus, soluble reactive phosphorus, nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, organic nitrogen, and chlorophyll *a* (surface water only).

In addition to these parameters, New recorded several other measurements of lake health. Secchi disk, light transmission, and oxygen saturation are single measurements made in the epilimnion. New measured dissolved oxygen and temperature at one-meter intervals from the surface to the bottom, and performed a plankton tow from the 1% light level depth up to the water surface.

EIS Analytical Services, Inc. analyzed the water quality samples in accordance with procedures in *Standard Methods for the Examination of Water and Wastewater*, 19th Edition (APHA, 1995). PhycoTech, Inc. enumerated the plankton sample and identified plankton species to the generic level. Under their enumeration procedure, PhycoTech examines plankton tow samples at a greater level of magnification than the level utilized by the CLP. As a consequence PhycoTech identified some organisms that would be missed using the CLP protocol. For their purposes of the TSI calculation, New omitted those small organisms that would likely be missed by the CLP. This will allow for better comparison between the 2001 data set and previous CLP data sets. The Results section includes a full list of organisms identified by PhycoTech. Appendix G outlines PhycoTech's plankton enumeration protocol.

Results

Table 11 and 12, and Figure 48 present the results of the August 10, 2001 assessment of Bass Lake. Appendix H details the laboratory results.

Table 11. Results of the 2001 Lake Water Quality Assessment of Bass Lake.

Parameter	Epilimnetic Sample (3ft)	Hypolimnetic Sample (17ft)	Indiana TSI Points (based on mean values)
pH	8.3	7.4	-
Alkalinity (mg/L)	53	57	-
Conductivity (umhos)	210	220	-
Secchi Depth Transparency (ft)	3.2	-	6
Light Transmission @ 3 ft	20%	-	4
1% Light Level (ft)	13.67	-	-
Total Phosphorous (mg/L)	0.11	0.14	3
Soluble Reactive Phosphorous (mg/L)	<0.05	<0.05	0
Nitrate-Nitrogen (mg/L)	<0.1	<0.1	0
Ammonia-Nitrogen (mg/L)	<0.05	<0.05	0
Organic Nitrogen (mg/L)	1.7	0.42	3
Oxygen Saturation @ 5 ft.	90%	-	0
% Water Column Oxic	100%	-	0
Plankton Density (#/L)	6.4×10^7*	-	25
Blue-Green Dominance	Yes	-	10
Chlorophyll *a* (µg/L)	7.2	-	-
TSI Score			**51**

*Omits those organisms that would not be visible using CLP plankton enumeration methodology.

Table 12. Results of 2001 plankton population sampling in Bass Lake.

SPECIES	ABUNDANCE (#/L)
Blue-Green Algae (Cyanophyta)	
Anabaena sp.	3.5×10^5
Aphanocapsa sp.	5.8×10^5
Aphanothece sp. (colony)	5.8×10^5
Chroococcus sp.	1.9×10^5
Lyngbya sp.	4.7×10^7
Merismopedia sp.	3.9×10^5
Oscillatoria sp.	3.9×10^5
Gomphosphaeria sp.	3.3×10^5
Microcystis sp. (colony)	6.6×10^6
Microcystis sp. (single)*	3.0×10^7
Non-motile blue-greens*	1.6×10^8
Synechococcus sp.*	1.9×10^8
Cylindrospermopsis sp.*	2.1×10^6
Green Algae (Chlorophyta)	
Dictyosphaerium sp.*	1.9×10^5
Mougeotia sp.*	7.7×10^5
Oocystis sp.	1.9×10^5

Scenedesmus sp.	$7.7x10^5$
Tetraedron sp.*	$7.1x10^9$
Non-motile *Chlorococcales*	$1.9x10^5$
Diatoms (Bacillariophyceae)	
Cyclotella sp.	$3.8x10^5$
Melosira sp.	$1.1x10^6$
Navicula sp.	$1.9x10^5$
Synedra sp.	$1.4x10^6$
Other Algae	
Misc. microflagellate*	$3.1x10^7$
Cryptomonads (Cryptophyta)	
Rhodomonas sp.	$1.9x10^5$
Zooplankton	
Bosmina longirostris	7.0
Daphnia sp.	0.7
Diaphanosoma	5.2
Calanoid copepodid	1.5
Leptodiaptomus	3.0
Nauplii	0.8
Total	$7.6x10^9$

*Indicates those species that were removed from the sample population when calculating the ITSI score.

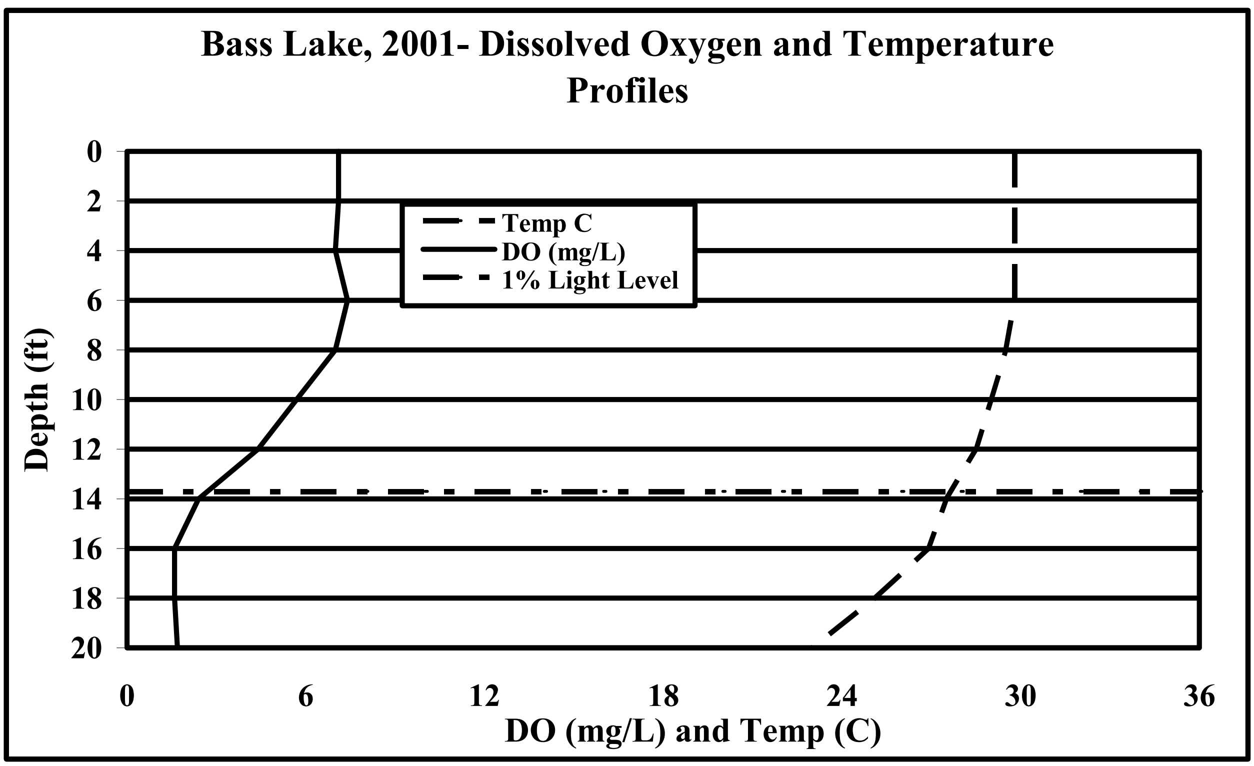

Figure 48. Dissolved oxygen and temperature profile for Bass Lake, August 10, 2001.

As the temperature profile indicates (Figure 48), Bass Lake was slightly stratified at the time of sampling. The top 10 feet (3 m) of the water column are isothermic, maintaining a temperature of approximately 28.5 °C. Below 10 feet (3 m), water temperature drops. Density differences associated with the colder water limit, if only slightly, any mixing of the upper layer with the lower layer of water. The temperature profile obtained during the August 10, 2001 sampling is consistent with the temperature profile developed for the 1995 and 1999 Clean Lakes Program sampling events.

The upper portion of the Bass Lake water column is well oxygenated. Oxygen saturation in the top 8 feet (2.4 m) of the water column ranges from 90 to 100%. Below 8 feet (2.4 m) the D.O. concentration drops. Below 12 feet (3.6 m), the D.O. concentration drops to a level that may stress lake biota (< 4.0 mg/L). Despite this, the water column does not become anoxic at any depth, maintaining concentrations above 1 mg/L throughout the water column.

Nutrient concentrations measured in Bass Lake on August 10, 2001 are similar to the concentrations observed during the 1995 and 1999 assessments. Soluble reactive phosphorus, nitrate-nitrogen, and ammonia-nitrogen concentrations were below the laboratory detection limit. In contrast total phosphorus and organic nitrogen concentrations were high. The hypolimnetic total phosphorus concentration was slightly higher than the epilimnetic concentration. Epilimnetic concentration of organic nitrogen was higher than the hypolimnetic concentrations. The ratio of total nitrogen to total phosphorus in the epilimnion was approximately 15.5:1 suggesting that Bass Lake is phosphorus limited.

The Secchi disk depth and light transmission measurements indicate that water clarity was poor at the time of sampling. Secchi disk depth was 3.2 feet (1 m) which is consistent with historical Secchi disk depth measurements. Water clarity impaired light transmission. Only 20% of the incident light penetrated Bass Lake's water column to a depth of three feet (0.9 m). The 1% light level of 13.7 feet (4.2 m) marks the lower limit at which light is sufficient for plant growth. Based on the depth-volume curves (Figure 42), Bass Lake's photic zone, the zone capable of supporting life, occupies over 90% of the water column. Phytoplankton that sink below this level will likely die unless transported via water column mixing to the upper layers of the lake where photosynthesis can again occur.

The lake's dense plankton community likely played a role in the decreased water clarity observed on August 10. The lake possessed a high chlorophyll *a* concentration of 7.2 μg/L, suggesting the presence of algae at the time of sampling. The results of the plankton tow confirm this presence. At the time of sampling, Bass Lake supported a fairly dense algal community with 6.4×10^7 organisms present per liter of water (Table 11). The plankton analysis indicated that Bass Lake was experiencing blooms of *Microcystis*, *Anabaena* and *Lyngbya*. These species belong to the blue green algae group. Blue green algae are considered nuisance algae and are associated with poor, or eutrophic, water quality. Blue greens dominated the Bass Lake algal community accounting for approximately 93% of the community.

Water Quality Discussion

To evaluate the results of the 2001 sampling, the following paragraphs: 1. compare the 2001 results to results of recent Indiana Clean Lakes Program assessment of all Indiana lakes as well as some accepted limnological standards; 2. examine the 2001 results within the context of historical assessments to elucidate any trends; and 3. evaluate the 2001 data using the Indiana Trophic State Index and the Carlson Trophic State Index.

Comparison to Other Indiana Lakes

To put the Bass Lake 2001 results in context, it is useful to compare the results to other Indiana lakes. Table 13 shows the median, maximum, and minimum values of selected water quality parameters for 355 Indiana lakes sampled from 1994 to 1998 by the Indiana Clean Lakes Program (Jones, 1996). (The Indiana Clean Lakes Program samples all public freshwater lakes in the state on a 5 year rotating basis. The data set below represents one full rotation.) The values for each parameter are mean concentrations of the eplimnetic and hypolimnetic samples.

Table 13. Comparison of 2001 Bass Lake assessment to one full rotation of the Indiana Clean Lakes Program sampling (355 lakes).

	Secchi disk (ft)	**NO_3 (mg/L)**	**NH_3 (mg/L)**	**TKN (mg/L)**	**TP (mg/L)**	**SRP (mg/L)**	**Chl. *a* (μg/L)**
Median	5.9	0.025	0.472	1.161	0.097	0.033	5.33
Maximum	30.0	9.303	11.248	13.794	4.894	0.782	230.9
Minimum	0.3	0.022	0.018	0.230	0.001	0.001	0
Bass Lake	**3.2**	**<0.1***	**<0.05***	**1.1**	**0.125**	**<0.05***	**7.2**

* Values were below laboratory detection limits. EIS laboratory detection limits are higher than those utilized by the Indiana CLP.

Based on this comparison, Bass Lake, in general, has worse water quality than most Indiana lakes. Bass Lake's Secchi disk depth was lower than most Indiana lakes, indicating that most Indiana lakes are clearer than Bass Lake. In addition, Bass Lake possessed higher concentrations of total phosphorus (TP) and chlorophyll *a* (Chl. *a*) than most Indiana Lakes. High chlorophyll *a* and total phosphorus concentrations suggest Bass Lake is more productive than most Indiana lakes. Bass Lake's total Kjeldahl nitrogen levels are similar to most Indiana Lakes.

Ammonium levels were good in Bass Lake at the time of sampling. As Table 13 shows, the Bass Lake ammonium concentration was low compared most Indiana lakes. Ammonium is a byproduct of the decomposition of organic materials. High ammonium levels are typically found in a lake's hypolimnion where decomposition occurs most frequently. Bass Lake's ammonium concentration in its hypolimnion was the same as the ammonium concentration in its epilimnion, suggesting little decomposition was occurring at the time of sampling.

Comparison with Vollenweider's Data

Richard Vollenweider conducted limnological studies on numerous lakes in the 1970's. As a result of his studies, Vollenweider established general ranges for relating water quality parameters to lake productivity or trophic state. (Refer to the Introduction portion of this section for a full discussion of trophic states.) Lake managers often use Vollenwieder's ranges as *general guidelines* for comparison with data collected on a specific lake. Table 14 presents the results of Vollenweider's work. The values in Table 14 are mean values from each trophic range.

Table 14. Mean values of some water quality parameters and their relationship to lake production (after Vollenweider, 1975).

Parameter	Oligotrophic	Mesotrophic	Eutrophic	Hypereutrophic
Total Phosphorus (mg/L or ppm)	0.008	0.027	0.084 *	> 0.750
Total Nitrogen (mg/L or ppm)	0.661	0.753 *	1.875	-
Chlorophyll *a* (µg/L or ppb)	1.7	4.7 *	14.3	-

The asterisks mark the ranges in which the Bass Lake concentrations of total phosphorus, total nitrogen, and chlorophyll *a* lie. Bass Lake's total phosphorus concentration suggests Bass Lake is a eutrophic lake, while its total nitrogen and chlorophyll *a* concentrations place the lake in the mesotrophic category. The Bass Lake concentrations fall in the high portion of the respective trophic ranges, with each concentration exceeding the mean for each range as shown in Table 14.

Examination of Water Quality Trends

The various lake assessments conducted on Bass Lake over the years illustrate snapshots of the lake's water quality. While these snapshots provide useful information on the conditions at the time the data was collected, examination of the trends in these water quality parameters over time may be more meaningful in evaluating the lake's water quality. The Bass Lake Historical Results section presented a review of historical data for trends in Bass Lake's water quality from the 1970's to 1999. Table 15 adds the results of the most recent sampling (August 2001) to the historical data to determine if these trends continue. The Indiana State Board of Health, Stream Water Pollution Control Board, the entity originally responsible for lake water quality measurements, recorded the 1975 and 1977 data. The Indiana Department of Environmental Management was responsible for the 1988 sampling, while the Indiana Clean Lakes Program collected the 1995 and 1999 measurements. J.F. New & Associates conducted the 2001 assessment. Concentrations in the table reflect averages of the epilimnetic and hypolimnetic samples.

Table 15. Comparison of water quality parameters from 1975 to 2001.

Parameter	8/18/75	9/6/77	8/16/88	8/7/95	7/27/99	8/10/01
Ammonium–Nitrogen (mg/L)	0.25	1.3	0.14	0.29	0.018	<0.05
Nitrate-Nitrogen (mg/L)	<0.1	<0.1	0.54	0.02	0.02	<0.1
Total Organic Nitrogen (mg/L)	1.1	1.0	2.0	2.1	0.826	1.06
Total Phosphorus (mg/L)	0.015	0.7	0.08	0.075	0.062	0.125
Light Transmission @ 3 ft	65%	19%	20%	28%	21%	20%
% Water Column Oxic	100%	100%	100%	86%	73%	100%
Secchi Disk Transparency (ft)	3.5	2.4	1.2	2.0	2.3	3.2

In general, adding the 2001 data to the historical data does not elucidate any new trends; many of the same trends discussed in the historical water quality portion of the document continue in 2001. Nitrate concentrations are historically low in Bass Lake and that trend continued in 2001. Nitrate concentrations exceeded the laboratory detection limit in only one lake assessment

(1988). Similarly, ammonium concentrations in Bass Lake are lower than most other Indiana lakes for the most part. Both the 1999 and 2001 ammonium concentrations fell below the respective laboratory detection limits. This indicates that either little decomposition was occurring at the time of sampling or algae are effectively using available ammonium in the water column. Given its well-oxygenated water column, the release of ammonium from the hypolimnion likely does not occur on Bass Lake with the same regularly that it does on other, better stratified Indiana lakes.

In contrast to the dissolved components of the water quality assessments, Bass Lake concentrations of total organic nitrogen and total phosphorus, which include the particulates of each, are relatively high. The 2001 data continue the trend of generally increasing total phosphorus concentrations. The current level of total phosphorus is of concern. It exceeds the median total phosphorus concentration in Indiana lakes and falls in the eutrophic range when compared to Vollenweider's data. High levels of phosphorus indicate the potential for algae and rooted plant growth is high.

The total organic nitrogen levels in 2001 are consistent with those found during lake assessments in the 1970's and 1999. The total organic nitrogen data suggests a shallow inverse parabolic trend with total organic nitrogen levels increasing from the 1970's to the late 1980's/mid 1990's and then decreasing again in the late 1990's and early 2000's. Current levels of total organic nitrogen are consistent with those found in the average Indiana lake and are low enough to place the lake into the mesotrophic (moderately productive) category according to Vollenweider's data.

The 2001 measures of water clarity (Secchi disk depth and light transmission) are also consistent with historical measurements and do not suggest the development of any new trends. Light transmission at 3 feet is poor in Bass Lake with all of the measurements, except the 1975 measurement, falling below 30%. Similarly, Secchi disk depth measurements indicate poor water clarity. Although the 2001 measurement is slightly higher than several of the measurements recorded in other years, the 2001 measurement should be viewed as being consistent with historical measurements given the high variability in Secchi disk transparency. Anecdotal evidence from Bass Lake residents suggests that water clarity varies widely in the summer depending upon the day of the week. Turbidity from heavy weekend boating extends well into the middle of the following week. The 2001 measurement was recorded on a Thursday. Consequently, the result may be better than if the measurement has been made on Monday or Tuesday of the same week. While it was not available for this analysis, a mean of weekly measurements made throughout the summer would provide a better approximation of water clarity in Bass Lake.

Although no trend exists with the percentage of the water column that is oxic data (Table 11), this data combined with the current and historical temperature profiles highlight an important characteristic about Bass Lake's water quality. Historical temperature profiles (Figure 44) indicate that Bass Lake's water column is partially stratified at times and unstratified (or completely mixed) at other times throughout the summer. This pattern of stratification and destratification is not unusual on shallow lakes. On warm, calm, sunny summer days, the surface waters of the lake heat up. Deeper waters remain cool compared to the surface waters. Cooler water is denser than warmer water. This density difference causes the lake to stratify or form layers based on the density differences. The warmer, lighter surface layers are thus isolated from the colder, heavier bottom layer; in other words, the lake is stratified.

On shallow lakes, cooler, windier days can cool surface waters enough to eliminate the temperature difference and therefore the density differences between the surface and bottom layers of the lake. The lake then destratifies, and the whole water column freely mixes. On shallow lakes with long wind fetches and those with heavy boat traffic, like Bass Lake, wave energy facilitates the destratification process. This pattern repeats itself throughout the summer.

This pattern of stratification/destratification can have important implications for Bass Lake's water quality, particularly when the lake's lower waters lack oxygen during a period of stratification. The 1995 and 1999 assessments indicate that at the time of those samplings, the lake was weakly stratified. In addition, a portion of the lake's hypolimnion during those assessments was anoxic (lacked oxygen). Under anoxic conditions, phosphorus that is bound to the iron in the lake's bottom sediments can be released into the water column. This released phosphorus is in the dissolved, bioavailable form (SRP). Because the lake was weakly stratified, water density differences prevented the SRP in the lake's lower layer from being quickly transported to the lake's surface waters. If the lake could maintain the stratification, the bioavailable SRP would remain trapped in the lake's hypolimnion. It could not reach the lake's algae, which typically reside in the lake's upper layers where sufficient light is available for photosynthesis. (Some diffusion of nutrients up through the water column occurs in stratified lakes. However, the amount of nutrients transported via diffusion is relatively small compared to the amount that can be transported via water column mixing.) Unfortunately, as the historical evidence suggests, it is not likely that the lake retained the weak stratification observed during the 1995 and 1999 assessments. Once the lake destratified and water density difference was eliminated, this phosphorus was mixed throughout the water column and became readily available to algae in the lake's photic zone.

Even under oxic conditions, phosphorus bound to bottom sediments may facilitate algae growth through a different mechanism. Anecdotal evidence and water clarity measurements suggest Bass Lake's bottom sediments are regularly resuspended. Bass Lake's natural morphometry (its shallowness and long fetch) makes the lake's bottom sediment susceptible to regular resuspension. The heavy boat traffic exacerbates the problem. Phosphorus bound to these bottom sediments may be released even under oxic conditions should the water's pH be high enough (generally above 9). Given the high density of phytoplankton on the lake, periods and pockets of intense photosynthesis would not be uncommon on Bass Lake. Intense photosynthesis activity could increase local pH to levels that exceed 9, thus facilitating the release of phosphorus from sediments suspended in the water column. The phosphorus, in turn, enables the growth of additional algae. Although more data would be necessary to prove conclusively that this occurs on Bass Lake, the hypothesis is not unreasonable.

Because the agencies/programs responsible for lake water quality assessments changed the methodology for evaluating algae between the 1988 and 1995 Bass Lake assessments, it is difficult to use the data to elucidate any trends in the lake's algae density and population. However, the assessments do show that blue green algae typically dominate Bass Lake by midsummer. In all but one of the historical lake assessments, blue green species dominated the plankton tows. Blue greens also dominated the plankton community in 2001.

Many blue green algae are nuisance species, capable of forming visible scums on the lake. Blue greens thrive in warm, nutrient laden water. Some are colony-forming species making the control of these algae by zooplankton, algae's primary predator, difficult. Some blue green algae such as *Microcystis* and *Anabanea* produce neurotoxins and hepatotoxins that, if ingested in large quantities, can cause harm or even death to livestock and wildlife. In extremely rare cases, the toxins have also caused harm to humans. While there are no national or international standards for blue green algae, the World Health Organization guidelines recommend keeping blue green algae concentrations below $2.0x10^7$ cells per liter to prevent short term effects from algal toxins; IDNR recommends concentrations below $1.0x10^8$ cells per liter to prevent long term effects (Jill Hoffman, personal communication). Blue green algae concentration in Bass Lake on August 10, 2001 exceeded both of these thresholds.

The dominance of blue greens in Bass Lake is not surprising. The high concentration of nitrogen and phosphorus create ideal conditions for blue green algae blooms. In addition, the mechanisms described above provide a regular fresh supply of bioavailable phosphorus to growing algae.

The presence of *Cylindrospermopsis* sp. in Bass Lake is of concern. *Cylindrospermopsis* is an exotic, relatively small member of the blue green algae group. Like most blue green algae species, *Cylindrospermopsis* is most likely to occur in fairly productive lakes that possess high nutrient concentrations, as Bass Lake does. Until this year, limnologists believed the *Cylindrospermopsis's* range was limited to the southeastern portion of the U.S. In June 2001, the IDNR reported a bloom of *Cylindrospermopsis* at Ball Lake in Steuben County. Because *Cylindrospermopsis* produces a hepatotoxin like some other members of the blue green algae group and because the hepatotoxin has been associated with gastroenteritis, nausea, vomiting and liver failure, IDNR along with the Indiana state Department of Health and the Steuben County Health Department issued a health advisory for Ball Lake as a precautionary measure.

The concentration of *Cylindrospermopsis* found in Bass Lake during the August 10, 2001 sampling effort was small compared to the concentrations reported at Ball Lake. (Ball Lake posses a concentration of 340,000 cells per milliliter of water compared to 38,197 cells per milliliter in Bass Lake.) Despite this, lake residents should take the discovery of *Cylindrospermopsis* in Bass Lake seriously and work to create lake conditions that inhibit or limit *Cylindrospermopsis* growth. This would include efforts to reduce nutrient (phosphorus and nitrogen) loading to the lake. As will be discussed later, lake residents do not have control over all nutrient sources, but lake residents have some ability to limit nutrient loading to the lake. Appendix I provides an IDNR informational news release on *Cylindrospermopsis*.

Indiana Trophic State Index

Based on the 2001 data, Bass Lake possesses an Indiana Trophic State Index score of 51. (Table 11 provides a calculation of the score.) Bass Lake received points for possessing high total phosphorus and organic nitrogen and for exhibiting poor water clarity. Bass Lake has historically received points for these same parameters. The plankton density and the dominance of blue green algae in the plankton community added the remainder of the points.

Table 16 adds the 2001 Bass Lake assessment to the historical assessments shown in Table 10. Table 17 also correlates the TSI score to its corresponding trophic state as expressed in Table 7. The data suggests that Bass Lake water quality improved in the 1990's compared to its condition in the 1970 and 1980's. The 2001 assessment shows a reversal in this trend.

Table 16. Summary of Indiana TSI scores for Bass Lake, 1975-2001.

Year	TSI Score	Trophic State
1975	36	Eutrophic
1977	39	Eutrophic
1988	42	Eutrophic
1995	20	Mesotrophic
1999	27	Mesotrophic
2001	51	Hypereutrophic

As discussed previously, the trend illustrated in Table 16 may be the result of the Indiana TSI's heavy reliance on algae in its calculation. From 1975-2001 investigators utilized three different collection and enumeration methods. In 1975, 1977 and 1988, biologists collected two plankton tows. IDEM modified the plankton collection methods following 1988. In 1995 and 1999, the Clean Lakes Program (CLP) collected a single plankton tow. New followed CLP collection methodology using a single tow from the lake's 1% light level to the surface; however, Phycotech, who analyzed the plankton community for New used a different enumeration procedure than that which CLP uses. Interestingly, the resultant trophic state correlates well with the algae collection and enumeration methodology used. The lake scored as eutrophic in 1975, 1977 and 1988 using the original methodology. In 1995 and 1999, using a different algal collection methodology the lake rated as mesotrophic. The lake scored as hypereutrophic in 2001 when New utilized a different enumeration procedure. Although the evidence is circumstantial, it supports the hypothesis that the ITSI may weight algal parameters too heavily, minimizing the importance of other water quality parameters in evaluating the lake's overall ecological health. Given this, the Indiana TSI may not be the most appropriate means for measuring Bass Lake's trophic condition.

Carlson Trophic State Index

Carlson's Trophic State Index provides another perspective on the Bass Lake data. Unlike the Indiana TSI, Carlson's TSI does not rely heavily on algae. When scored using Carlson's equations, the 2001 Bass Lake data suggests the lake falls in either the eutrophic or hypereutrophic categories (Table 16). This is consistent with the historical evaluation of Bass Lake using the Carlson TSI. The 2001 total phosphorus data suggest the potential for increased algae growth and therefore increased productivity of the lake. Despite this, the 2001 chlorophyll *a* data, which is an indicator of algae, suggests the lake is slightly less productive than indicated by the Secchi disk transparency and total phosphorus data. The Bass Lake's high non-algal turbidity may play a role in inhibiting algae growth to its full potential suggested by the high phosphorus concentrations.

Table 17. Carlson's Trophic State Index Score for Bass Lake, 1975-2001.

Year	Secchi Disk Transparency	Total Phosphorus	Chlorophyll *a*
1975	Hypereutrophic	Mesotrophic	-
1977	Hypereutrophic	Eutrophic/Hypereutrophic	-
1988	Hypereutrophic	Hypereutrophic	-
1995	Hypereutrophic	Hypereutrophic	Eutrophic
1999	Hypereutrophic	Hypereutrophic	Hypereutrophic
2001	Hypereutrophic	Hypereutrophic	Eutrophic

Caution should be exercised when Bass Lake's Secchi disk data is used to evaluate the lake within the context of the Carlson TSI. Unlike Bass Lake, Carlsons's study lakes possessed low non-algal turbidity. When Carlson observed a decrease in Secchi disk transparency in one of his lakes, it was primarily due to high densities of algae. Thus Secchi disk transparency was tightly linked to lake productivity. Because in Bass Lake suspended sediment likely contributes to the observed poor Secchi disk transparencies, the link between Secchi disk measurement and lake productivity is not as strong in Bass Lake as compared to Carlson's lakes. Simply put, Carlson's Secchi disk TSI likely overestimates the true productivity of Bass Lake.

Water Quality Summary

Bass Lake may best be described as a eutrophic lake with the potential for exhibiting hypereutrophic characteristics. Historically and currently, the lake possesses high concentrations of phosphorus and nitrogen. Results of the 2001 sampling indicate that Bass Lake has a higher concentration of total phosphorus in the water column than most Indiana lakes. Additionally, total phosphorus concentrations appear to be increasing over the years. The high level of nutrients supports a fairly dense algal population. The algal data suggest several nuisance blue green species that are associated with high nutrient concentrations were in bloom at the time of sampling.

The lake also possesses poor water clarity. The current and historical Secchi disk transparency depths were low compared to other Indiana lakes. In addition, the lake has a record of poor light transmission through its water column. While the dense algae blooms noted above can decrease water clarity, the heavy boating and natural morphometry of Bass Lake (long wind fetch) contribute to the lake's poor water clarity. The heavy boating may also accelerate the natural stratification and destratification process that occurs on many shallow lakes, thus increasing frequency of water column mixing and decreasing water clarity. Heavy boating, wind activity, and stratification/destratification may be facilitating the release of phosphorus from the sediment, thereby increasing the algae density. This, in turn, would decrease water clarity. These factors favor overall poor water clarity.

The lake may partially benefit from the poor water clarity. By limiting the amount of light available to the photosynthesizing algae, the abundance of suspended sediment in the lake may be limiting the algae from reaching their full potential given the high amount of nutrients in the water column. When Bass Lake 2001 data is compared to Vollenweider's data, the total phosphorus concentration suggests the lake is eutrophic while the chlorophyll *a* concentration (an indicator of actual algae) suggests the lake is mesotrophic. Evaluating the data using the Carlson's TSI reveals the same pattern. Carlson's TSI using total phosphorus indicates the lake is hypereutrophic, while Carlson's TSI using chlorophyll *a* indicates the lake is eutrophic. In both cases, it appears given the amount of total phosphorus in Bass Lake, the algae populations should be greater. This suggests that something other than phosphorus is limiting algal growth in Bass Lake. The lake's poor water clarity may be that limiting factor for algal growth.

This does not mean lake residents should work to maintain or even decrease water clarity by increasing boating activity. While it may be preventing algae from reaching the maximum, pea soup type, densities that would be possible given the abundance of phosphorus in the lake, the poor water clarity is not poor enough to prevent blooms of nuisance algal species. Additionally, increasing boating activity, as described above, may actually increase phosphorus concentration in the lake. Ultimately, the high phosphorus concentration must be controlled to decrease the frequency of and potential for nuisance algal blooms.

FISHERIES

A review of published literature revealed several reports documenting the condition of the Bass Lake fish community. Blatchley (1900) provides one of the first published records of the lake's fishery. His work includes only a species list. (Appendix J presents this list along with a listing of species found during other surveys.) Three decades later in 1935 and 1936, the Indiana Department of Conservation (now Indiana Department of Natural Resources) conducted two fish population studies on the lake. These original studies provide some insight into the lake's fishery prior to 1972 when the Indiana Department of Natural Resources (IDNR) began an intense study of Bass Lake. Since 1972, the IDNR has conducted many fisheries studies on the lake. The IDNR has performed three creel surveys to determine harvests and angler preference. The following paragraphs summarize many of these published reports.

<u>IDNR Fisheries Surveys</u>

1972

In 1972, the IDNR conducted a fisheries survey on Bass Lake (Robertson, 1973). The study consisted of 96 hours of gillnetting and two hours of electrofishing. The 1972 survey resulted in the collection of 529 fish representing 13 species. The dominant species collected were channel catfish (44.6%), gizzard shad (15.7%), quillback (15.5%), white bass (7.4%), carp (6.6%), and walleye (3.2%). With exception of channel catfish and white bass, popular game fish (yellow perch, white crappie, bluegill, and largemouth bass) were present but in small numbers. Yellow perch, white crappie, bluegill, and largemouth bass comprised only 3.4% of the total sample in 1972.

A comparison between the 1972 survey and seining operations done in 1935 and 1936 revealed that the lake's fish community structure had changed. Survey methodology undoubtedly differed between the two efforts; however, several generalizations can be made. For example, the lake's rough fish population declined from the 1930's to 1972. Quillback and carp accounted for over 75 % of the lake's fish population based on the 1935/1936 survey. In contrast, less than 40% of the lake's fish community consisted of quillback, carp, and gizzard shad in 1972. The channel catfish population in Bass Lake increased significantly from the 1930's to 1972. The IDNR reports channel catfish stocking occurred on the lake in the 1940's (Robertson, 1992). Channel catfish dominated the 1972 survey results, while biologists collected only 2 channel catfish in the 1935/1936 effort.

Robertson (1973) concludes his report with several recommendations. First, Robertson recommends the stocking of walleye and northern pike in Bass Lake. These species are popular among anglers and would add two additional top predators to the lake's fish community. The IDNR implemented this recommendation in the spring of 1974 by releasing one million northern pike fry into Bass Lake. Robertson's works also highlights the turbid water conditions as compared to the conditions described in the 1935/1936 report. He attributed the increased turbidity to the increase in boating activity on Bass Lake. Robertson's suggestions to reduce the turbidity in the lake included zoning areas for "high speed operation" and other areas for "idle speed only".

1974

The IDNR conducted a second fisheries survey in 1974 (Robertson, 1975). Three hundred eighty four hours of gillnetting and 2 hours of electrofishing yielded a catch of 661 fish representing 15 species. Channel catfish, white bass, gizzard shad, and quillback dominated the catch with results similar to the community structure found during the 1972 survey. One distinct difference between the surveys was that game species increased in relative percentage from 58.6% in 1974 to 73.3% in 1974. Robertson (1975) attributes the difference to the increase of white bass from 7.4% to 17.9% of the total sample. Over 92% of the white bass sample were of harvestable size. The percent of walleye in the survey (approximately 5% of the catch) remained consistent with that found in 1972. Most walleye ranged in size from 14 inches (36 cm) to 16 inches (41 cm).

1979

In 1979, the IDNR conducted a third fisheries survey on Bass Lake (Robertson, 1980). Sampling consisted of three hours of electrofishing, 288 hours of gill netting, and 288 hours of trap netting. The survey yielded a total of 602 fish from 13 species. The most abundant species collected were channel catfish (33.6%), white crappie (8.8%), and black crappie (8.3%). Biologists did not collect any northern pike.

The 1979 survey showed several similarities with previous surveys. For example, the 1979 survey indicated that Bass Lake still possessed an excellent channel catfish fishery. Biologists collected only one bluegill and no largemouth bass during the 1979 effort. This is consistent with previous surveys where biologists collected one bluegill and one largemouth bass in 1972 and two bluegills and three largemouth bass in 1974.

The 1979 survey contrasted with previous surveys in some respects. In 1972, biologists collected only six white crappie (1% of the total catch). By 1979 white crappie was the second most abundant fish collected in the IDNR fisheries work. The 1979 survey also highlighted changes in the white bass population. White bass accounted for only 5.2% of the total catch in 1979 compared to 17.9% in 1974. White bass' relative abundance in 1979 is more consistent with that observed in 1972.

In his 1979 report, Robertson repeats many of the same recommendations made in previous reports. Establishment of an idle zone to limit damage done to aquatic vegetation by the heavy boating activity on the lake tops the list of recommendations. The IDNR emphasized the importance of local resident cooperation in achieving this goal. Other important recommendations made in the 1979 survey include the construction of fish attractors and continuing the predator stocking program. The IDNR implemented the last suggestion by stocking the lake with over 1,800 northern pike fry in the fall of 1979 and over 4 million walleye fry in 1980.

1980 - 1985

From 1980 to 1985, IDNR biologists conducted five spot checks to monitor and evaluate the fish stocking efforts on Bass Lake. The IDNR stocked 1,000,000 northern pike fry in 1974, 1,803 northern pike fingerlings in 1979, 4,010,000 walleye fry in 1980, 1,950,000 walleye fry in 1982, and 67,000 walleye fingerlings in 1982. To perform the spot checks, biologists deployed 2 or 3 gill nets for 1 or 3 days resulting in 48-96 hours of total effort.

Table 18 summarizes the results of these spot checks. In 1980, biologists collected 3 northern pike from the 1979 stocking effort. They did not collect any walleyes from the release that occurred earlier that year. Biologist tripled the length of gill net deployment in 1982. This increased effort resulted in the collection of seven walleyes from the 1980 stocking as well as several walleyes from other age classes. Biologists did not collect any walleyes from the most recent 1982 stocking. For the first time, however, biologists collected two northern pike: one young of the year and one adult from the 1979 stocking.

Table 18. Summary of Spot Checks for Walleye and Northern Pike in Bass Lake from 1980-1985.

Year	Species	#	Stocking Class	Total Length of Gill Net Deployment	Catch per Hour of Effort
1980	Northern pike	3	1979	48	0.0625
	Walleye	0	-	48	-
1982	Northern pike	2	1-1979; 1-other	144	0.0139
	Walleye	10	7-1980; 3-other	144	0.0694
1983	Northern pike	0	-	72	-
	Walleye	21	20-1982; 0-other	72	0.292
1984	Northern pike	1	?	96	0.0104
	Walleye	22	18-1982; 4-other	96	0.229
1985	Northern pike	0	-	96	-
	Walleye	8	Most from 1982	96	0.083

Source: IDNR Fisheries Reports 1980-1985.

Despite a decrease in the hours of gill net deployment, biologists collected 20 walleyes in August of 1983. All of these were from the 1982 stocking effort. In 1984, the IDNR slightly increased the gill net deployment from the 1983 level. The 1984 effort yielded 24 walleyes. Twenty of the 24 were from the 1982 stocking effort; four were from the 1980 stocking effort. Biologists also collected one northern pike in 1984. Using the same methods in 1985 as they did in 1984, IDNR biologists collected eight walleyes, most of which were from the 1982 class.

From these spot checks, one can draw a few generalizations. First, the IDNR walleye stocking effort appears to be supplementing the existing native walleye population. Although the number of walleyes caught per unit of effort varied from year to year, biologists collected walleyes in each year except 1980. Most of the walleye collected came from the 1982 stocking class. Robertson (1984, 1985, 1986) hypothesizes that the use of fingerlings in the 1982 stocking class increased the overall survival of the stocked fish. The spot checks also confirm that walleyes are successfully reproducing in Bass Lake. In contrast, the northern pike stocking effort appears to be less successful with biologists collecting only 6 pike total from 1980 to 1985. Despite this apparent lack of success, one of the two northern pike collected in 1982 was a young of the year suggesting some natural reproduction is occurring or at least did occur at some point in the lake.

IDNR biologists reported the presence of other species collected in the gill nets during these spot checks. Many of the same species that dominated the fisheries surveys completed in the 1970's dominated the overall catches in the early 1980's as well. These species include channel catfish, gizzard shad, white crappie, and yellow perch. Approximately 5 to 15% of the catches consisted of walleye. Bluegill and largemouth bass continued to be minor components of the fishery. With the exception of the 1985 survey in which bluegill comprised 7.5 percent of the catch, biologist collected none or very few of these species in each of the survey years.

Some caution should be exercised when comparing the results of the spot checks to those of the 1970's since biologists only utilized gill nets in the spot checks. Depending upon the placement of the nets, gill nets tend to favor the collection of pelagic species. The studies conducted in the 1970's utilized electrofishing and trap netting to capture species that inhabit other habitat types. The overall species composition reported in the spot checks may be skewed toward pelagic species.

1986

The IDNR released 3,776,450 walleye fry into Bass Lake in 1986. In an attempt to better measure the immediate success of the stocking, IDNR biologists conducted a limited fisheries survey (Dexter, 1986) in the fall following the stocking. The 1986 survey differed from previous stocking program monitoring efforts in that biologists utilized boat-mounted electrofishing equipment rather than gill nets to sample fish. This methodology change would allow for the collection of more young fish and thus obtain a better understanding of how many fry survive the first few months following stocking. Focusing only on walleye for this survey, biologists collected 29 individuals from three age classes: 0+, II+, and III+. Twenty of the individuals were young-of-the-year (YOY) from the spring stocking effort. Size measurements indicated that none of the remaining nine walleye were stocked. However, the presence of these young fish (age II+ and III+ classes) suggests that the lake's walleye were successfully reproducing. Based on the results of this survey, the IDNR concluded that they should continue to stock walleye and that current gill net monitoring methods should be supplemented with electrofishing methods to fully evaluate the survival and growth of stocked walleye.

1987

The IDNR did not stock the lake with walleye in the spring of 1987; consequently, the IDNR continued to utilize gill nets to monitor the walleye stocking program. Biologists deployed four gill nets for two days or a total of 192 hours of netting during the 1987 survey. The effort resulted in the collection of 13 walleye, most of which were not stocked by the IDNR. The low catch rate (0.677 walleye per hour of effort) was lower than any of the reported in the table above (Table 18). Robertson (1987) recommends a continuation of the walleye stocking program. He also notes that if fry stocking continues to produce less than satisfactory results, the IDNR should consider fingerling stockings.

1988-1990

In the spring of 1988, 1989, and 1990, the IDNR added 4,035,000, 4,088,175, and 4,070,200 walleye fry, respectively, to Bass Lake (Robertson, 1991). Implementing the recommendations made by Dexter (1986) IDNR biologists monitored the success of these stockings by conducting nighttime electrofishing surveys in the fall of each year following the stockings.

Table 19 summarizes the results of these surveys. In 1988, the survey effort yielded the collected of 274 representing 6 age classes. Most (nearly 83%) were from the 1988 spring stocking. Several individuals from the age II+ class may have been from the 1986 stocking effort. Individuals from other age classes suggest that natural reproduction is occurring in Bass Lake.

Table 19. Summary of nighttime electrofishing walleye surveys on Bass Lake, 1988-1990.

Monitoring Year	# of Walleyes Collected	# of YOY Walleye	Electrofishing Effort	YOY caught per hour	Total walleye caught per hour
1988	274	227	5 hours	56.8	54.8
1989	352	214	6 hours	35.7	58.7
1990	297	167	6 hours	27.8	49.5

Source: IDNR Fisheries Reports 1988-1990.

In 1989, biologists caught more walleye per hour of survey effort; however fewer of these were YOY. This indicates that the 1989 stocking effort was slightly less successful in terms of initial survival of the fry compared to the 1988 stocking. Lake conditions at the time of stocking such as the water quality or abundance of predator species can impact the success of any stocking effort. Biologist collected individuals from seven age classes during the 1989 monitoring, suggesting that stocked individuals are surviving and confirming that natural reproduction is occurring in Bass Lake.

The 1990 results were consistent with the results from the two previous years. Both the total catch of walleye per hour and the YOY catch per hour rates decreased slightly from previous years. Despite this slight decrease, Robertson (1991) calls the YOY survival "excellent" in 1990. Biologists collected individuals from six age classes in the 1990 survey reaffirming conclusions made from previous surveys about the success of the stocked and native walleye populations.

1991

After a decade of walleye monitoring, IDNR biologists conducted a full fisheries survey on Bass Lake in 1991 (Robertson, 1992). The 1991 survey consisted of 288 hours of gill netting, 288 hours of trap netting, and 2 hours of nighttime electrofishing. Biologists captured 381 fish representing 17 species during the survey. The results of the survey were consistent with those full fisheries surveys conducted in the 1970's. Channel catfish, quillback, white crappie, gizzard shad, white bass, and walleye were the primary species collected. Game species accounted for over 75% of the catch; however, as in past surveys, biologists collected few largemouth bass and bluegills. White crappie abundance was similar to that observed in 1979. White bass abundance in the 1991 survey mirrored its relative abundance noted in 1972 and 1979 surveys. The relative abundance of rough fish (primarily carp, gizzard shad, and quillback) was lower than that observed in the 1970's. Recommendations from the 1991 report include the reduction in annual walleye stocking, the implementation of a creel survey in 1992, and the establishment of a gentleman's agreement to limit high-speed boat operation to the hours of 9 a.m. to 5 p.m.

1992, 1996, 2001

The IDNR continued annual stockings of walleye fry and IDNR biologists continued to conduct fall nighttime electrofishing surveys to monitor the success of these stockings. The IDNR published the results of the 1992, 1996, and 2000 fall electrofishing efforts in their 1992, 1996, and 2001 creel survey reports (Robertson and Page, 1992; Riedel et al., 1996; and Brindza, 2001). Table 20 summarizes the results of the 1992, 1996, and 2000 fall electrofishing efforts. The 1992 sampling effort yielded 217 walleye, 71.4% of which were YOY walleye. This indicated that the survival of walleye fry appeared to be excellent. In contrast, biologists collected only 16 YOY walleye (out of a total of 129 walleye) in the 1996 sampling effort. Riedel et al. (1996) suggest the increased abundance of crappie, decreased abundance of gizzard shad, and poor environmental conditions at the time of stocking influenced walleye survival in 1996. Results from the 2000 sampling effort were similar to those from the 1992 sampling effort. In 2001, biologists captured 344 walleye, 306 (89%) of which were YOY.

Table 20. Summary of nighttime electrofishing walleye surveys on Bass Lake, 1988-2000.

Monitoring Year	# of Walleyes Collected	# of YOY Walleye	Electrofishing Effort	YOY caught per hour	Total walleye caught per hour
1992	217	155	6 hours	25.8	36.2
1996	129	16	6 hours	2.7	21.5
2000	344	306	4 hours	76.5	86.0

Source: IDNR Fisheries Surveys.

<u>Creel Surveys</u>

1992

IDNR biologists had recommended the conducting a creel survey to establish angler preference on Bass Lake in several of the published walleye spot check reports of the 1980's. In 1992, the IDNR implemented this recommendation by conducting a creel survey (Robertson and Page, 1992). As outlined by the report's authors, the objectives of the survey were to:

1. Determine the number, sizes, and species of fish harvested.
2. Determine fishing pressure.
3. Determine the number of walleye and largemouth bass caught and released.
4. Determine the species of fish preferred by anglers.
5. Determine angler's county and residence.
6. Determine walleye and largemouth bass population size.

In 1992 anglers harvested over 18,000 fish from Bass Lake in nearly 35,000 hours of fishing during the creel period. This harvest rate constitutes a fishing pressure on the lake of approximately 25.8 hours/acre, which Robertson and Page call "light". Anglers collected fish from ten species. Anglers caught mostly black and white crappies, walleye, channel catfish, and white bass. When asked about their fishing preference, over 41% of anglers did not have a species preference. Of those expressing a fishing preference, most were fishing for walleye or crappie. Despite the dominance of channel catfish in the lake's fish community, only 3% of anglers reported a preference for channel catfish. In terms of residence, the creel survey revealed that most Bass Lake anglers (37.5%) lived on Bass Lake. Another 24.9% resided in other places around Starke County. Out of state anglers accounted for slightly less than 15% of the total angler population.

The 1992 creel survey included a population study component. During March and April of 1992, IDNR biologists collected nearly 1,100 fish in several large trap nets or by electrofishing methods. Biologists fin-clipped and released all walleyes and largemouth bass collected in the traps or via electrofishing. Of the 687 fin clipped walleye, anglers reported catching 41 during the creel period. From this, IDNR biologists estimated that Bass Lake contained approximately 7,596 walleyes or 5.7 walleyes per acre. Anglers did not report the catch of any fin-clipped largemouth bass during the creel survey; consequently, IDNR biologists could not estimate largemouth bass population size.

1996

In 1996, IDNR biologists conducted a second, smaller scale creel survey at Bass Lake (Riedel et al. 1996). In general, the 1996 creel survey goals were the same as goals for the 1992 creel survey, except the 1996 did not include a population study component. Anglers reported harvesting over 8,500 fish at Bass Lake in nearly 12,000 hours of fishing, resulting in a fishing pressure of 8.9 hours/acre. Anglers took more bluegills than any other species (35% of the total fish harvested). Anglers also collected large numbers of channel catfish, crappie, and walleye. When asked about fishing preference, over 51% of the parties had no preference. Those anglers with preferences preferred crappie and walleye. Seven percent of those interviewed reported that they were fishing for channel catfish. The published report does not record any information concerning angler residence.

2000

In 2000, the IDNR conducted a third creel survey at Bass Lake (Brindza, 2001). Methods and goals of the 2000 creel survey were the same as those for the 1996 creel survey. Brindza (2001) estimated that anglers harvested 8,335 fish in 17,061 hours of fishing. This constitutes a fishing pressure of approximately 12.7 hours per acre. Crappie comprised 80% of the harvested catch followed by channel catfish (7%) bluegill (5%), then walleye (5%). Figure 49 summarizes the results of the 2000 harvest as well as the 1992 and 1996 harvests.

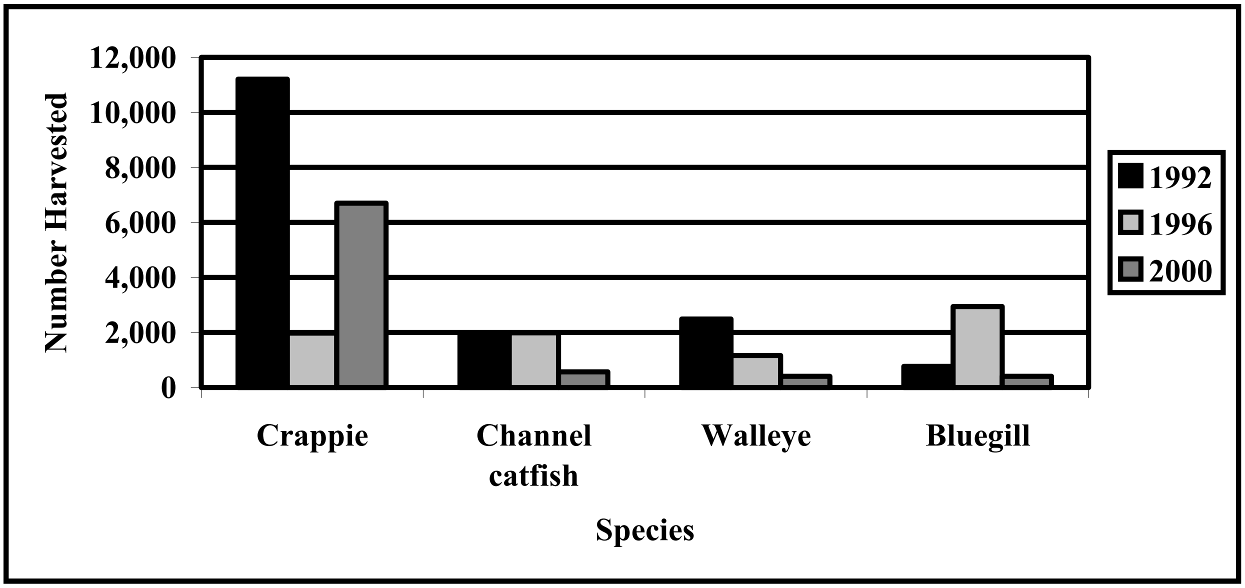

Figure 49. Number of species harvested by year.

When asked about fishing preference, 58% indicated that they were fishing for anything. Of those fishing for a certain species, most fished for walleye or crappie. Most anglers lived in Starke County (excluding lake residents). Many anglers came from Porter, Lake and Jasper Counties with these anglers representing 16.1%, 15.1%, and 12.3% of the total interview, respectively. Bass Lake residents accounted for only 6.6% of the anglers interviewed during the creel survey, while out-of-state anglers represented just 1.7% of the total interviewed.

The 2000 creel survey also included questions designed to elicit anglers' perceptions of the lake's fishery. When asked to rate their fishing experience, most (85%) anglers were satisfied with their experience. When asked to compare the lake's current fishery to what it was in the past, angler response differed somewhat compared to lake residents' responses in the resident survey. Approximately one third of those interviewed in the creel survey believed the quality of the lake's fishery is remaining constant. Slightly less than a third reported observing an increase in fishing quality, while 14% thought the fishery was declining. In contrast, the lake resident survey found residents were more likely to report a decrease in fishing quality than an increase.

Summary

Figure 50 summarizes the relative abundance of dominant fish species collected by IDNR biologists in Bass Lake from 1972 to 1991. Channel catfish were a primary component of the fish community in Bass Lake fisheries surveys. They dominated the IDNR's catch in 1972, 1974, 1982, 1984, and 1991. Robertson (1979) indicates that Bass Lake supported one of the best channel catfish fisheries in the state of Indiana. Crappie (black and white) were also an important component of IDNR fisheries surveys. Crappie dominated the catch in the 1979, 1985, and 1987 surveys. White bass were a major species collected by the IDNR biologists in 1972, 1974, 1979, and 1982. White bass were absent from the 1983 survey. However, their numbers increased in surveys conducted after 1983. With exception of the 1983 and 1984 surveys, the percentage of walleye collected by the IDNR has remained between two and six percent of each survey sample (Figure 51). (It is important to remember that the spot check

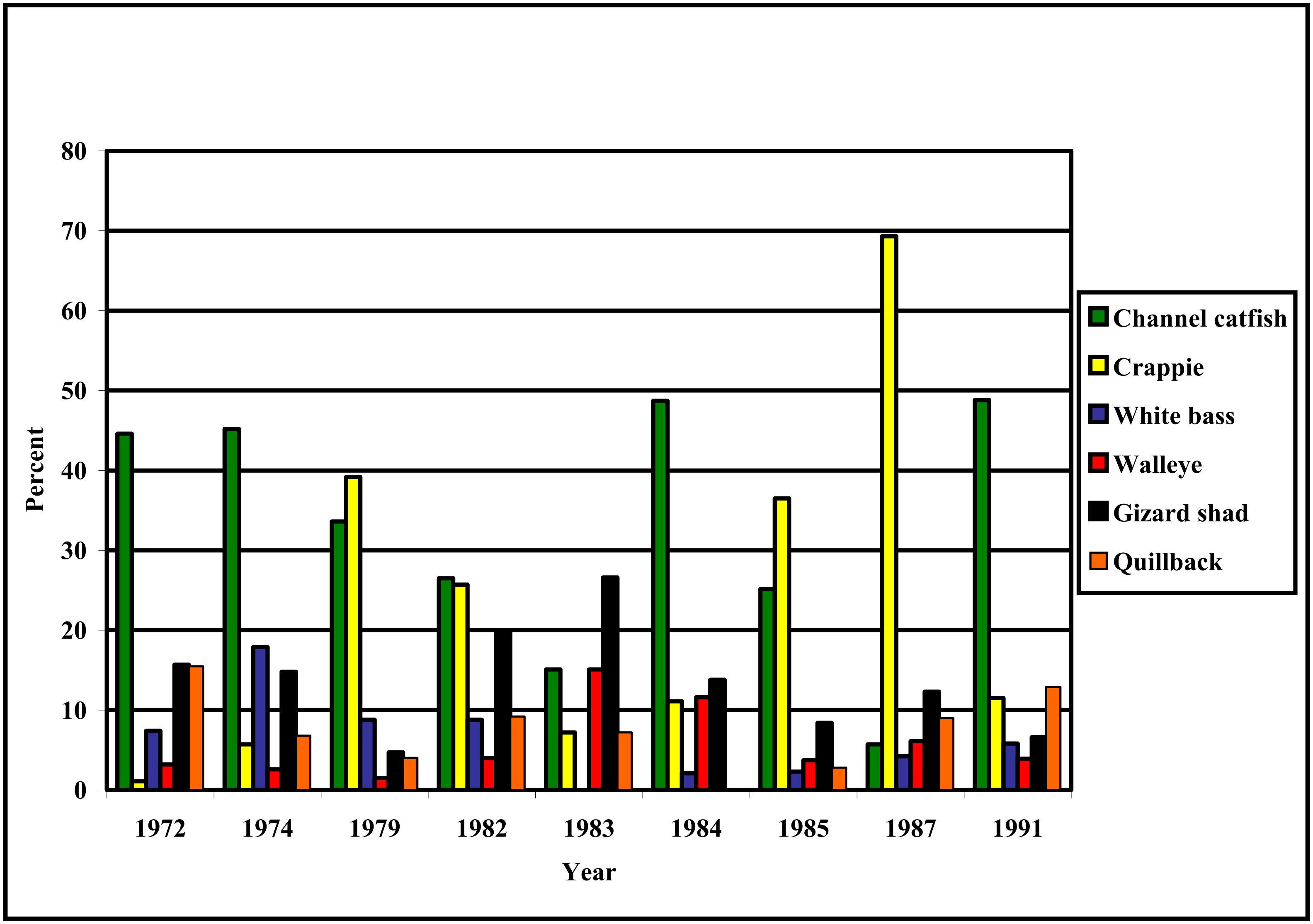

Figure 50. Relative abundance of dominant fish species in Bass Lake, 1972-1991. Data source: IDNR fisheries surveys.

surveys completed in the 1980's utilized different methods than the full fisheries surveys of the 1970's and 1991.) In general gizzard shad numbers were lowered in the late 1980's and early 1990's compared to the population numbers observed in the 1970's and early 1980's. The quillback population has fluctuated over the survey years.

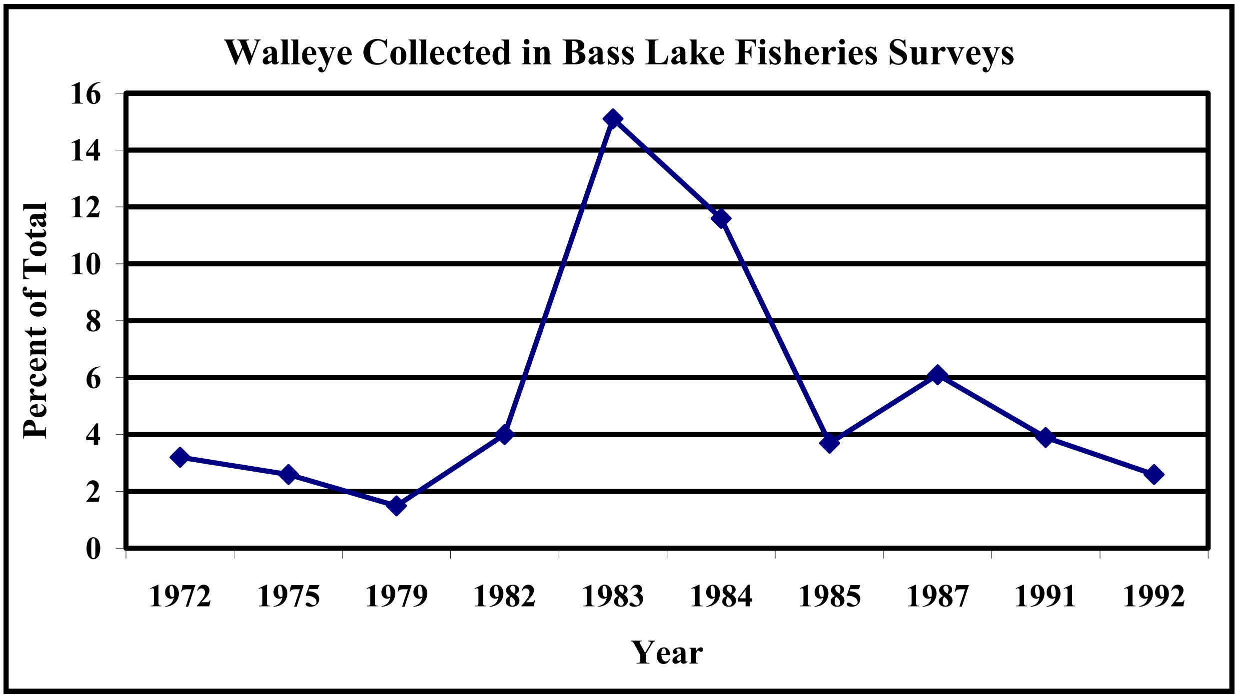

Figure 51. Percentage (percent of total sample) of walleye sampled in Bass Lake, 1972-1992. Data source: IDNR fisheries surveys.

In contrast to many other northern Indiana lakes, Bass Lake is almost devoid of bluegill and largemouth bass according to the fisheries surveys. Competition for food and spawning territory with species such as white bass, crappie, walleye and northern pike may be limiting bluegill and largemouth bass populations. Lack of aquatic vegetation, leading to insufficient spawning habitat, could also be contributing to low capture rates. Recent studies conducted by the Minnesota Department of Natural Resources reveal that spawning largemouth bass avoid developed shorelines in favor of spawning habitat adjacent to banks with little human activity (Pennaz, 2001). Nearly 90% of Bass Lake's shoreline is developed and few aquatic vegetation beds exist. These factors cause spawning largemouth bass to congregate near what little habitat remains. As a result, they are vulnerable to angling pressure and weather conditions that disrupt spawning.

The IDNR has heavily managed Bass Lake for walleye. The management includes annual stocking. Table 21 summarizes the walleye stocking program. As Table 21 shows, the IDNR has primarily stocked walleye fry; however, in 1982, biologists released walleye fingerlings as well. In general, fry survival, as measured by fall nighttime electrofishing surveys, has been excellent. The nighttime electrofishing collection rates for YOY walleye has ranged from a low of 2.7 fish per hour in 1996 to a high of 76.5 fish per hour in 2000 (Tables 19 and 20). Sampling efforts throughout the past three decades have confirmed that natural reproduction is occurring in the lake.

Table 21. Walleye stocking in Bass Lake, 1980 to 2000.

Year	Number	Size
1980	4,010,000	Walleye fry
1982	1,950,000	Walleye fry
1982	67,000	Walleye fingerlings
1986	3,776,450	Walleye fry
1988	4,035,000	Walleye fry
1989	4,088,175	Walleye fry
1990	4,070,200	Walleye fry
1991	4,035,000	Walleye fry
1992	4,031,425	Walleye fry
1993	2,017,500	Walleye fry
1994	3,018,650	Walleye fry
1995	2,023,350	Walleye fry
1996	2,024,525	Walleye fry
1997	2,018,650	Walleye fry
1998	2,017,500	Walleye fry
1999	2,075,050	Walleye fry
2000	1,854,150	Walleye fry

Data Source: IDNR fisheries surveys

While fry survival appears to be strong, the length and weight of walleye sampled from 1983 to 2000 have declined from surveys conducted in 1972 to 1982 (Figure 52). IDNR surveys conducted in 1972, 1974, 1979, and 1982 indicate that the average walleye captured was 16 inches (40.6 cm) and nearly two pounds. Since 1982, IDNR surveys reveal that the average walleye collected was just under 10 inches (25.4 cm) and weighed close to one pound. A variety of factors including low forage fish numbers, impaired walleye spawning and forage fish resting habitat, and fishing pressure/overharvesting may be contributing to this decline in the average length and weight of walleye sampled by IDNR biologists.

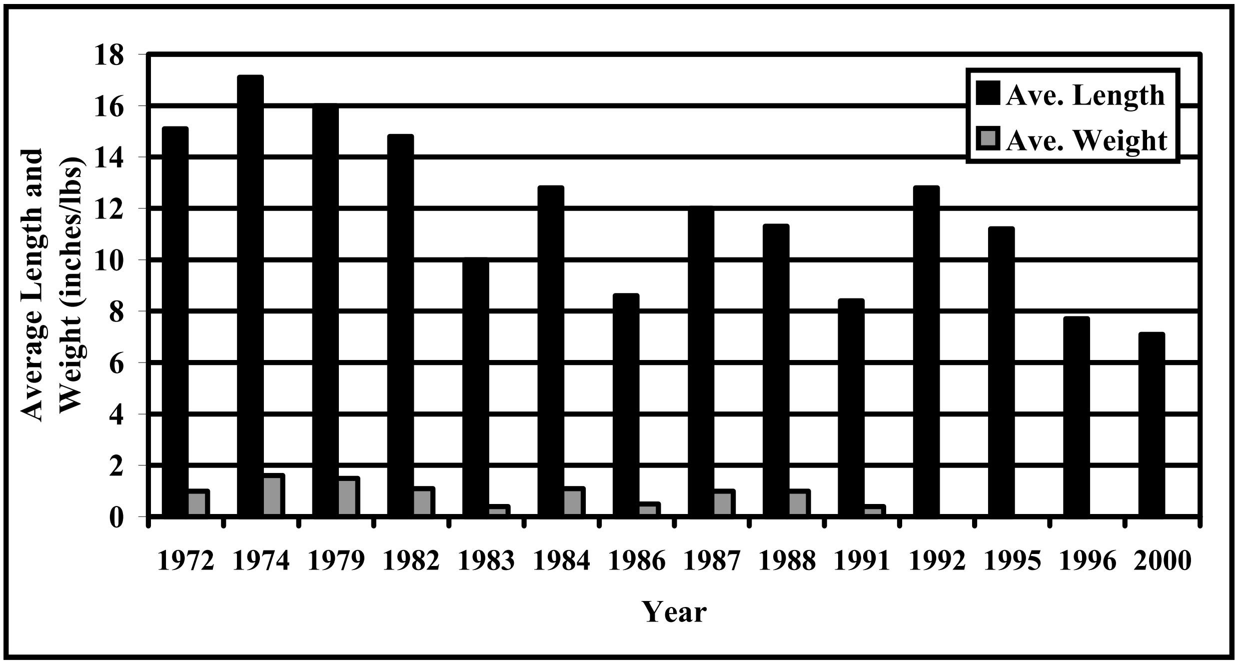

Figure 52. Average length and weight of walleye sampled in Bass Lake, 1972-2000. Weight for years 1992-2000 are not available. Data source: IDNR fisheries surveys.

In the summer of 2001, a survey conducted by J.F. New revealed that Bass Lake possesses a sparsely vegetated littoral zone. (See the Aquatic Plant Section for a full discussion of Bass Lake's aquatic plant community.) Because many fish species rely on aquatic plants for cover from predators, spawning habitat, and forage habitat, the lack of vegetation in the littoral zone may have implications on the fish community of Bass Lake. For example, northern pike spawn directly on vegetation in shallow water in early spring. The newly hatched northern pike fry feed on invertebrates and small fish associated with vegetation. Without sufficient littoral vegetation, the adult northern pike have limited spawning habitat, and the northern pike fry have limited food sources. Walleye also rely on vegetation when spawning. A lack of vegetation could limit reproductive success of mature walleye, making stocking necessary for the existence of a walleye fishery on Bass Lake. Additionally, the small forage fishes, upon which walleye feed, inhabit vegetated zones for protection. Without sufficient habitat, forage fish populations become stunted, reducing their ability to support top predators such as walleye. Black crappie prefer clearer water and abundant vegetation on which to spawn. Limited littoral vegetation may be the reason white crappie are historically more prevalent in Bass Lake than black crappie. These examples are a few of the many possible ways that the lack of littoral vegetation may affect the Bass Lake fish community structure.

Lake managers have successfully utilized a variety of artificial fish habitat structures in many lakes throughout the Midwest to combat a lack of aquatic vegetation. Although the presence of littoral vegetation is essential to the reproductive success of most game species in Bass Lake, artificial structures provide protection and suitable habitat for juvenile and adult fishes. Spaces in artificial structures are more important than surfaces. Small spaces offer cover to small fish while large spaces attract larger fish. The surfaces around the spaces provide a place for periphyton to attach and, thus, grow food to which forage fish are attracted.

Examples of artificial fish habitat structures include submerged brush piles, logs/tree trunks, bricks and hollow blocks. Submerged brush piles anchored by cinder blocks provide excellent fish habitat. These structures can create spawning surfaces and cover for a variety of species. Brush piles and trees vary in their ability to attract fish and overall durability. Christmas trees are abundant after the holidays and are often used as fish attractors. They are most attractive to crappie, although largemouth bass and sunfish species will also use them. After three to six years, the Christmas trees will deteriorate and need to be replaced. Hardwood brush lasts much longer. Largemouth bass typically utilize logs and tree trunks for habitat. If placed over other hard objects such as another log, rock, or bricks, logs create spaces for largemouth bass and other species. To enhance largemouth bass spawning, logs placed in the shallows will protect spawning bass, which prefer the comfort of structure. Many fisheries agencies also recommend bricks and hollow blocks. These structures have not worked as well as brush piles to concentrate game fish but they are more durable than brush piles. They primarily provide surfaces rather than spaces but if carefully tied together to create spaces, they are much more effective than single blocks.

It is important to consider the ecology of the targeted species before placing any artificial habitat in the lake. As mentioned above, different types of artificial habitat attract different species of fish. Residents should use the artificial habitat preferred by the species whose population they wish to enhance. In addition, where residents place the habitat matters. Many game species feed in shallow water during the evening and early morning hours and quickly escape to the comfort of deep water. Placing structures in 8-15 feet of water near Cedar Point, Gull Point, and Cranberry Point would create ideal habitat for crappie, bluegill, walleye and largemouth bass.

In conclusion, Bass Lake supports a good crappie, channel catfish, walleye, and white bass fishery. The creel surveys indicate that crappie, channel catfish, walleye, and bluegill are the most harvested fish (Figure 50). A lack of vegetation for several consecutive years may reduce the fishery unless artificial structures are strategically placed. Preferably, beds of native aquatic vegetation should be reestablished. The lake's conditions will continue to improve with conservation and restoration efforts in and around the lake.

AQUATIC MACROPHYTE SURVEY

Introduction

J.F. New & Associates (New) conducted a general macrophyte (rooted plant) survey of Bass Lake on May 29, 2001. The survey's purpose was to locate areas with high densities of submerged and emergent aquatic vegetation in the lake. Due to the limited scope of this LARE study, the survey consisted of a general reconnaissance in shallow areas of the lake. In areas possessing the greatest density of rooted plant growth (based on visual observation), New performed random rake grabs to determine the species present. New did not record quantitative measures of species abundance or percent cover. While this methodology has some shortcomings, it provides good information on the dominant species present and extent of coverage in the lake from which general management recommendations can be made. Before detailing the results of the macrophyte survey, it may be useful to understand the conditions under which lakes may support macrophyte growth. Additionally, an understanding of the roles that macrophytes play in a healthy, functioning lake ecosystem is necessary.

Conditions for Growth

Like terrestrial vegetation, aquatic vegetation has several habitat requirements that need to be satisfied in order for the plants to grow or thrive. Aquatic plants depend on sunlight as an energy source. The amount of sunlight available to plants decreases with depth of water as algae, sediment, and other suspended particles block light penetration. Consequently, most aquatic plants are limited to maximum water depths of 5 or 6 feet (1.5 to 1.8 m), but some species, such as Eurasian water milfoil, have a greater tolerance for lower light levels and can grow in up to 12 feet (3 m) of water. Bass Lake's shallow morphology suggests a strong ability to support aquatic plant growth. According to the depth-area curves Bass Lake (Figure 41), approximately 70 % of the lake is less than 5 feet (1.5 m) deep while nearly 90% of the lake is less than 12 feet (3.6 m) deep. Because Bass Lake supports only a limited aquatic plant community, factors other than depth are likely limiting plant growth in Bass Lake.

Water clarity affects the ability of sunlight to reach plants, even those rooted in shallow water. Lakes with clearer water have an increased potential for plant growth. Bass Lake's Secchi disk transparency has historically been less than most Indiana lakes, limiting the potential for rooted plant growth. New recorded a Secchi disk transparency measurement of 3.2 ft (1 m) during this study's sampling further supporting the idea that limited water clarity may be affecting the establishment of a healthy aquatic plant community in Bass Lake. (See the Water Quality Section for more details on water quality characteristics.)

Aquatic plants also require a steady source of nutrients for survival. Aquatic macrophytes differ from microscopic algae (which are also plants) in their uptake of nutrients. Aquatic macrophytes receive most of their nutrients from the sediments via their root systems rather than directly utilizing nutrients in the surrounding water column. Some competition with algae for nutrients in the water column does occur. The amount of nutrients taken from the water column varies for each macrophyte species. Because macrophytes obtain most of their nutrients from the sediments, lakes which receive high watershed inputs of nutrients to the water column will not necessarily have aquatic macrophyte problems.

The type of substrate present affects a lake's ability to support aquatic vegetation. Lakes that have mucky, organic, nutrient-rich substrates have an increased potential for plant growth compared to lakes with gravelly, rocky substrates. The substrate of Bass Lake consists largely of sand although areas of muck and clay substrate exist as well. While sandy substrates typically support healthy aquatic plant communities, this is only true when sufficient organic material is mixed in with the sand to provide a nutritional base for the rooted plants. The largest bed of aquatic vegetation on Bass Lake was noted in an area where organic matter was visibly present in the substrate. The second largest bed of vegetation on the lake occurs in an area possessing a mucky substrate. Much of Bass Lake's remaining sandy substrate may not contain enough organic material to support plant growth.

The forces acting on a lake's substrate also affect aquatic vegetation growth. Lakes that have significant wave action that disturb the bottom sediments have decreased ability to support plants. Disturbance of bottom sediment may decrease water clarity, limiting light penetration or may affect the availability of nutrients for the macrophytes. Wave action may also create significant shearing forces prohibiting plant growth altogether.

Boating activity may affect macrophyte growth in conflicting ways. Rooted plant growth may be limited if boating activity regularly disturbs bottom sediments. This is possible on Bass Lake given the popularity of boating among lake residents. Complaints about boating speed and personal watercraft further supports the hypothesis that some macrophyte growth may be limited by boating activity. Alternatively, boating activity in rooted plant stands of species that can reproduce vegetatively, such as Eurasian water milfoil, may increase macrophyte density rather than decrease it.

Ecosystem Roles

Aquatic plants are a beneficial and necessary part of healthy lakes. Plants stabilize shorelines holding bank soil with their roots. The vegetation also serves to dissipate wave energy further protecting shorelines from erosion. Plants play a role in a lake's nutrient cycle by uptaking nutrients from the sediments. Like their terrestrial counterparts, aquatic macrophytes produce oxygen which is utilized by the lake's fauna. Plants also produce flowers and unique leaf patterns that are aesthetically attractive.

Emergent and submerged plants provide important habitat for fish, insects, reptiles, amphibians, waterfowl, shorebirds, and small mammals. Fish utilize aquatic vegetation for cover from predators and for spawning and rearing grounds. Different species depend upon different percent coverages of these plants for successful spawning, rearing, and protection for predators. For example, bluegill require an area to be approximately 15-30% covered with aquatic plants for successful survival, while northern pike achieve success in areas where rooted plants cover 80% or more of the area (Borman et al., 1997).

Aquatic vegetation also serves as substrate for aquatic insects, the primary diet of insectivorous fish. Waterfowl and shorebirds depend on aquatic vegetation for nesting and brooding areas. Numerous aquatic waterfowl were observed utilizing the lakes as habitat during the macrophyte survey. Aquatic plants such as pondweed, coontail, duckweed, water milfoil, and arrowhead, also provide a food source to waterfowl. Duckweed in particular has been noted for its high protein content and consequently has served as feed for livestock. Turtles and snakes utilize emergent vegetation as basking sites. Amphibians rely on the emergent vegetation zones as primary habitat.

<u>Historical Surveys</u>

The published literature documenting Bass Lake's historical aquatic plant community is sparse. State Geologist, William Blatchley, provides an excellent overview of the lake's aquatic plant community in his 1900 report for the former Indiana Department of Geology and Natural Resources. The picture Blatchley paints of Bass Lake differs greatly from what exists there today. In his report, Blatchley (1900) notes the presence of 40 different aquatic species in and around the wet margins of the lake. (Blatchley calls his list a "partial" list based on only a few days spent on the lake; in other words, Bass Lake may have supported several other species as well.) The list includes ten species of pondweeds and over 15 species of emergents populating the lake's shoreline. Appendix K provides a complete listing of the species included in Blatchley's report.

Although Blatchley's work does not report quantitative data concerning species abundance or coverage, the qualitative descriptions in the report suggest Bass Lake's plant community was once a thriving and dominant component of the lake ecosystem. For example, Blatchley notes, given the lake's ideal sand and clay bottoms that "the lake flora is a very rich one, and worthy of extended study." In areas with muck substrates such as the bay east of Cranberry bay and the western shoreline of the northern basin, Blatchley admires "the luxuriant growth of aquatic vegetation." Blatchley also attributes Bass Lake's success as "one of the best and most noted fishing resorts of Indiana" to the "large amount of aquatic vegetation" in the lake. Blatchley even comments on the abundance of individual species in his 1900 work. The report includes words and phrases such as "occurs abundantly", "quite common", and "frequent" to describe the many of the individual species.

Most recent surveys provide a stark contrast to Blatchley's description of the Bass Lake aquatic plant community. IDNR fisheries biologists conducted limited aquatic plant surveys in conjunction with many of the full fisheries surveys from 1972 to 1991. Robertson (1973) reports the presence of only seven species in and along the lakeshore in 1972 compared to Blatchley's "partial list" of 40 species. These rooted plants covered only 1% of the lake's surface area. Additionally, Robertson notes that the "relatively weed-free condition of Bass Lake is not a natural condition." With the exception of an outbreak of Eurasian water milfoil in the early 1980's, the fisheries survey reports of 1974, 1979, and 1991 document conditions similar to those found in 1972. Based on these reports it appears that by the early 1970's the lake's aquatic plant community had deteriorated to the point where rooted plants covered only a very small portion of the lake's total surface area.

May 2001 Survey Results

With the exception of the occasional chara mat, only three small pockets of floating or submerged vegetation were noted during the survey. These areas are marked on Figure 53. Each of the areas is a cove protected on at least two sides from wave and wind energy. At the time of the survey, Area 1 exhibited the largest area of vegetation coverage. Dominant species in the cove include spatterdock and white water lilies. A limited amount of curly leaf pondweed was growing in deeper areas along the lakeward edge of the spatterdock bed. Spatterdock and water water lilies dominate Areas 2 and 3. Scattered Eurasian water milfoil plants vegetate the lakeward edge of the spatterdock/lily bed in Area 3. Appendix K provides a complete list of species observed during the 2001 sampling effort.

Approximately 90% or more of the Bass Lake shoreline is developed, and at least 80% of the shoreline lacks emergent vegetation (Figure 54). Natural shoreline exists in the northwest corner of the southern lobe of the lake. This area supports the remnants of a wooded wetland bordering the lake. Dominant overstory vegetation in the wetland includes silver maple (*Acer saccharinum*), American elm (*Ulmus americana*) and river birch (*Betula nigra*). Buttonbush (*Cephanthus occidentalis*), smartweed (*Polygonum* sp.), reed canary grass (*Phalaris arundinacea*), and dogwoods (*Cornus* sp.) vegetate the wetland understory. Cattails (*Typha* sp.), three square bulrush (*Scirpus americana*), rushes (*Juncus* spp.), and sedges (*Carex* spp.) occupy

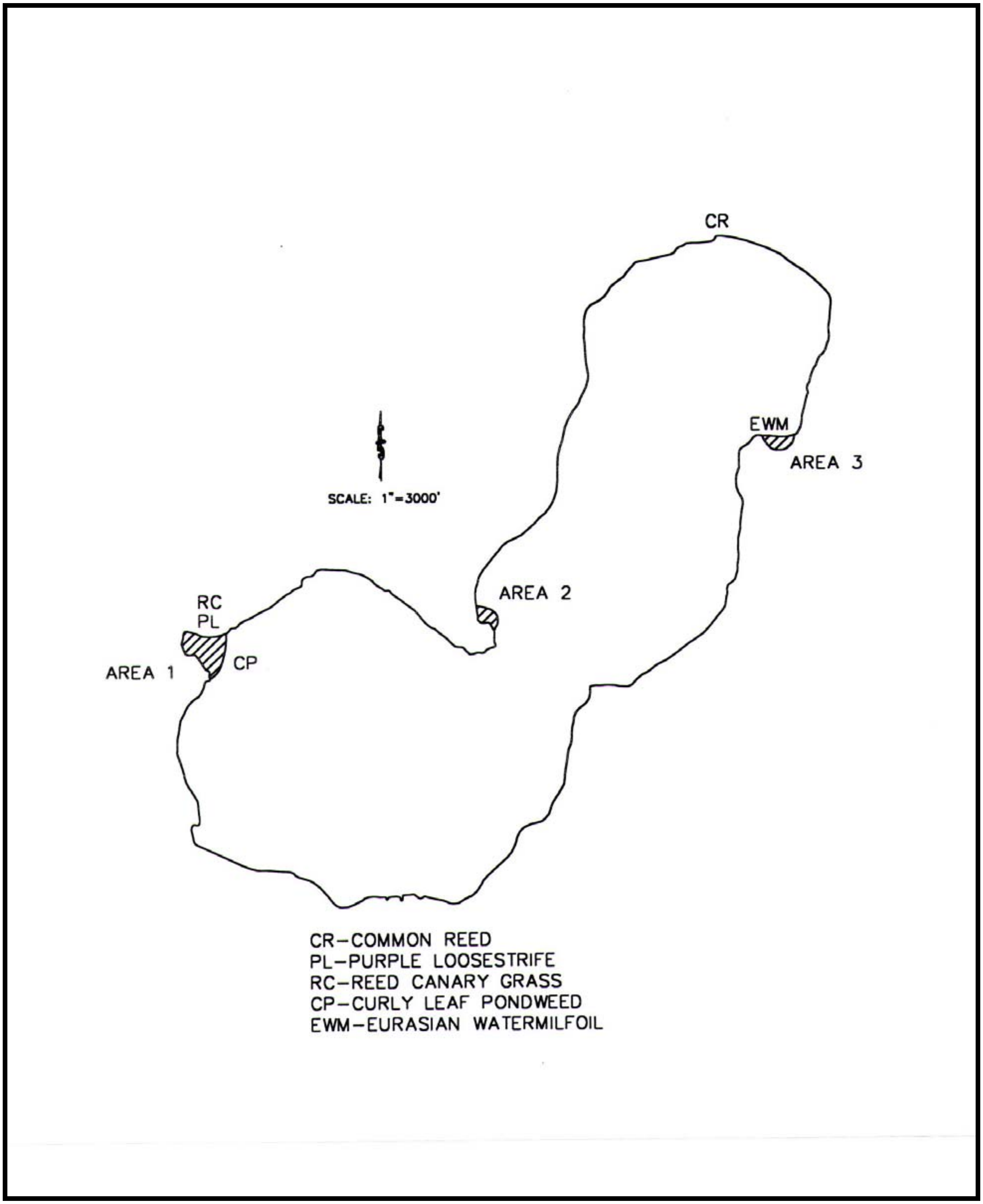

Figure 53. Vegetated areas located during 2001 vegetation sampling. Source of Base Map: U.S.G.S. 7.5 Minute Topographical Map.

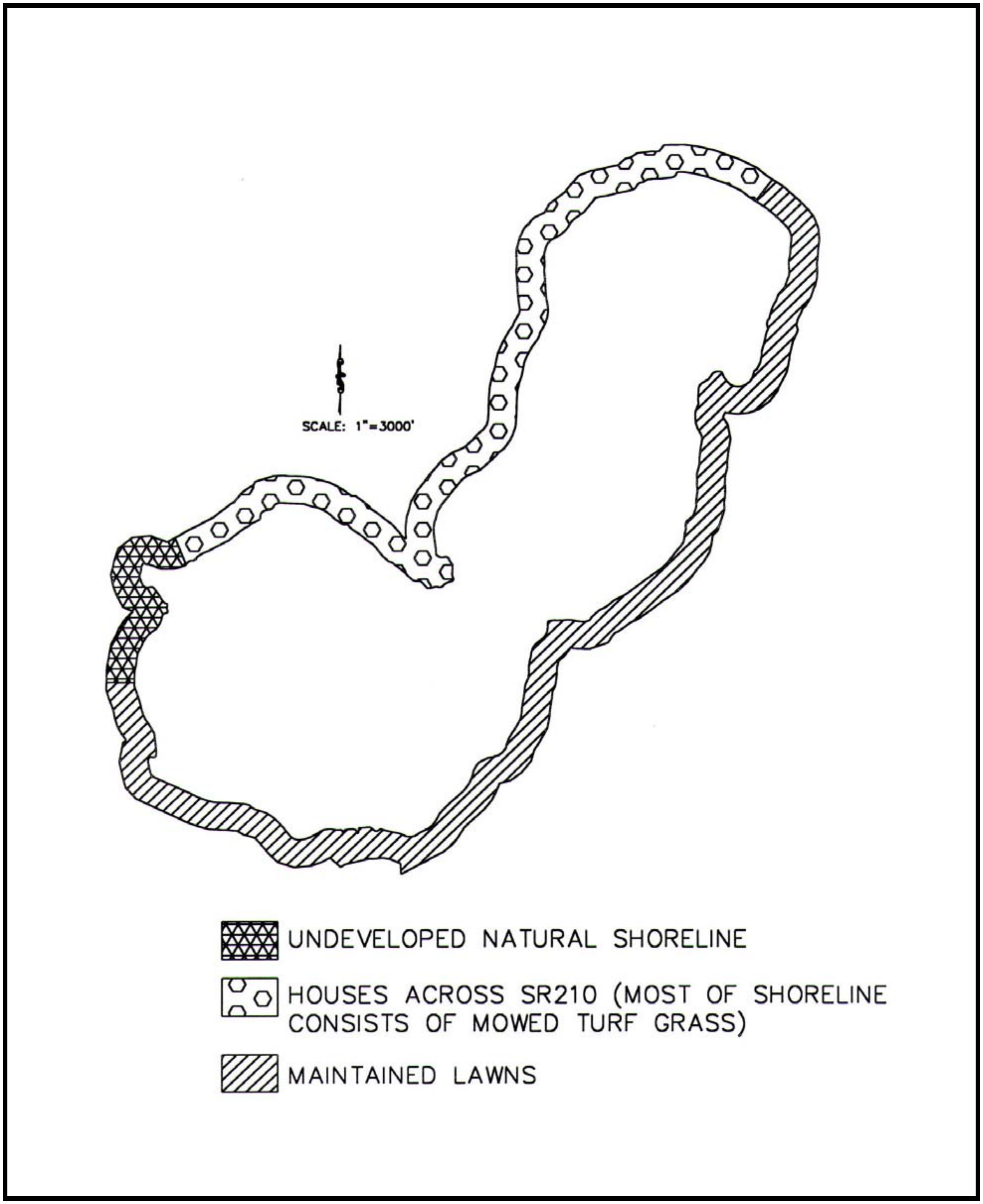

Figure 54. Shoreline vegetation observed around Bass Lake. Source of Base Map: U.S.G.S. 7.5 Minute Topographical Map.

shallow water between the wooded wetland habitat and the floating aquatics deeper water areas. This portion of the lake provides a glimpse of what the Bass Lake shoreline may have looked like prior to development.

Bass Lake supports five rooted exotic plant species, including two submerged species, Eurasian water milfoil and curly leaf pondweed, and three emergent species, reed canary grass, purple loosestrife, and common reed (*Phragmites australis*). Figure 53 maps the location of the Eurasian water milfoil and curly leaf pondweed. Purple loosestrife is scattered along the lake's edge. The greatest concentration of purple loosestrife occurs in the wetland on the northwestern edge of the lake's southern lobe. This wetland also harbors the greatest concentration of reed canary grass. Only a few common reed plants exist along the lake's northern edge.

Discussion

Bass Lake differs from many area lakes in that it supports an extremely limited rooted plant community. Several factors are likely involved in limiting rooted plant growth in Bass Lake. First, Bass Lake's water clarity may be too poor to support rooted plants. Bob Robertson, the IDNR Fisheries Biologist who staffed the Bass Lake Fisheries Station for several decades, believes water clarity is the biggest factor controlling aquatic plant growth in the lake (personal communication). Robertson notes that the water clarity has been poor over the last thirty years, and the absence of vegetation in the lake is not unusual. Robertson's claim of poor water clarity is supported by existing data. As stated in the Water Quality Section, historical Secchi disk transparency depths were commonly less than 3 feet. Given the poor water clarity, rooted plants may not be receiving sufficient light to survive.

Heavy boat and personal watercraft (PWC) usage may also play a role in limiting the growth of rooted plants in Bass Lake. According to the resident survey, approximately 78% of the respondents noted that they boated on the lake and approximately 43% used PWC on the lake. On a sunny summer day (July 15, 2001), lake residents observed nearly 200 boats on the lake during peak afternoon hours. Additionally, lake residents counted 915 boats with motors around Bass Lake, suggesting a potential for even greater usage on any given day. The wave action from these motorboats and PWC can shear aquatic vegetation. Boating activities also decrease water clarity, particularly in shallow lakes like Bass Lake, further reducing the potential for rooted plant survival.

Bass Lake's natural morphometry and setting may limit rooted plant growth as well. Bass Lake possesses a long fetch. On lakes with long fetches, winds whip across the lake surface creating wave action. These waves may be of sufficient force to prohibit rooted plant establishment. The wind/wave action may indirectly limit rooted plant growth as well by stirring bottom sediments, which, in turn, reduce water clarity and reduce the potential for rooted plant growth. Bass Lake's southwest to northeast orientation compounds the problem. Summer winds typically blow out of the southwest. Bass Lake's orientation is ideal for the creation of wind-driven waves. The lack of forested land (a natural windbreak), particularly along the lake's southern lobe, further exacerbates the problem.

Lastly, recent aquatic plant control methods may be in part responsible for the lack of rooted plants on the lake. According to IDNR Division of Fish and Wildlife records, two chemical applications occurred on Bass Lake in 1998 and 2000 to treat Eurasian water milfoil beds. The treatments included the application of Navigate at a rate of approximately 100 lbs/acre to the areas shown in Figure 55. Chemical applications rarely eliminate rooted plant beds. More typically, lakes require yearly or twice yearly applications to control nuisance stands of rooted plants to levels deemed acceptable by lake residents. In this case, however, it appears that the treatment (or at least the treatment in combination with other factors such as those listed above) has eliminated the largest bed of rooted plants.

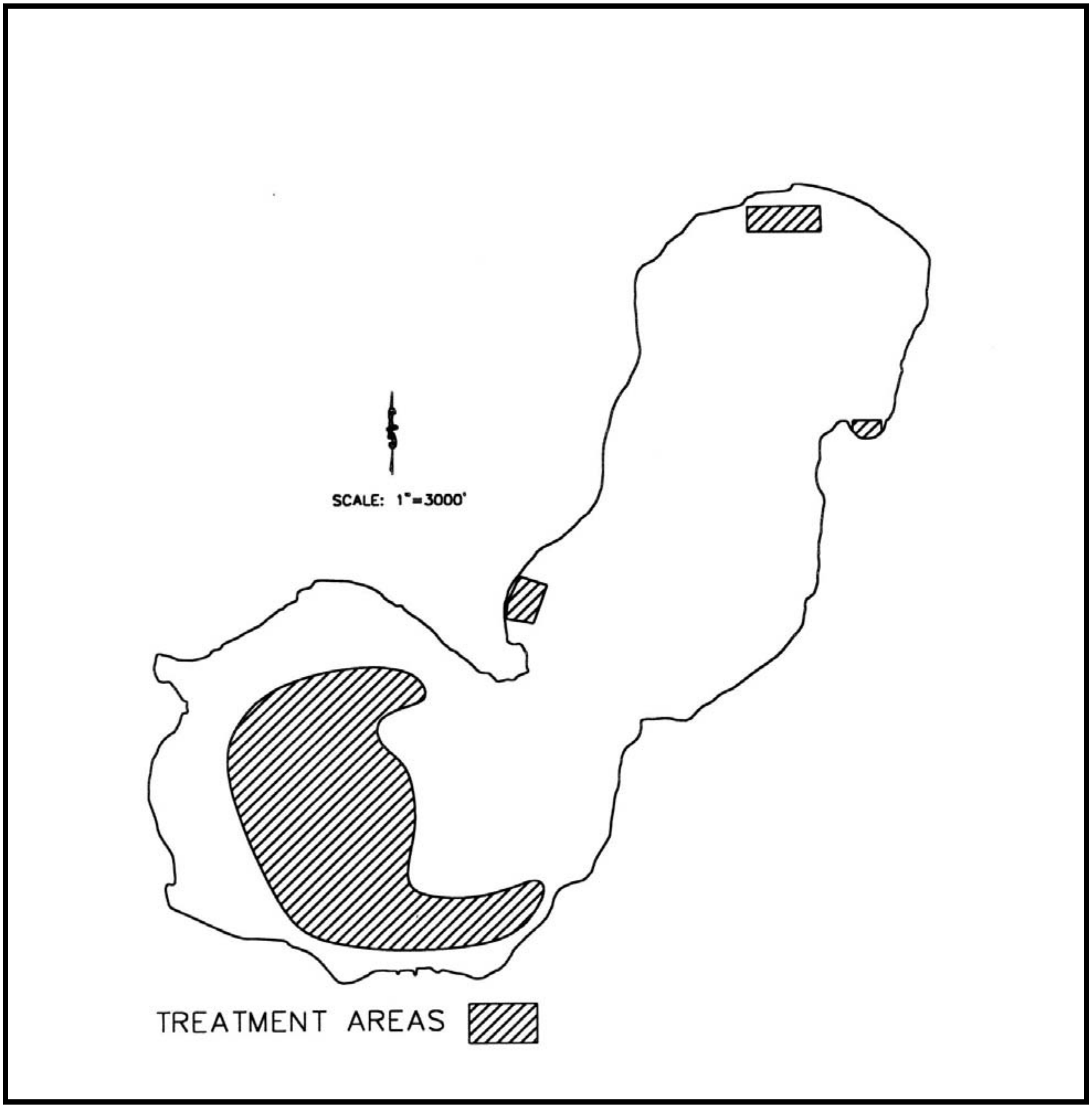

Figure 55. Location of chemical application for the removal of submergent aquatic vegetation. Source of Base Map: U.S.G.S. 7.5 Minute Topographical Map; Source of Data: IDNR Division of Fish and Wildlife permit file.

The lack of a rooted plant community in Bass Lake is of concern. As mentioned previously rooted plants are an integral part of a healthy lake ecosystem. The loss of these plants means the loss of the functions they perform. In the case of Bass Lake, the most critical functions are the role rooted plants play in stabilizing sediments and shorelines and providing fish spawning and resting habitat. Additional rooted plants in the lake would assist in preventing the disturbance of bottom sediments by wave action. Rooted plants would likely also improve the fisheries on the lake. Given that slightly less than 50% of the resident survey respondents stated that they fished on the lake, sustaining or even improving the lake's potential to support a fish community would be a worthy lake management goal.

The loss of Bass Lake's rooted plant community may also pose a financial cost to the Bass Lake community. IDNR creel surveys on Bass Lake indicate that a third or more of the anglers utilizing Bass Lake live in other counties and even other states. Should the quality of the Bass Lake fishery decline due to the loss of rooted plants, out-of-area anglers may chose to fish elsewhere. If this occurs, the local marina, convenience stores, and restaurants may experience a loss of income associated with those out-of-area patrons.

The presence of exotic species is also of concern in Bass Lake, although the populations of all five of the exotic species noted around Bass Lake are small. All five of these species are aggressive and have the potential to take over their respective habitats. For example, Eurasian water milfoil often grows in dense mats excluding the establishment of other plants. Once the plant reaches the water's surface, it will continue growing horizontally across the water's surface. This growth pattern can potentially shade other submerged species preventing their growth or establishment. Purple loosestrife easily out-competes many native wetland plants. If lake levels drop, purple loosestrife could expand its coverage into shallow areas of the lake. Once established, this species will thrive even if lake levels rise again.

These exotic plants provide few of the same functions that native species provide to the lake ecosystem. Native emergents provide a food source to waterfowl. Waterfowl typically avoid the three exotic emergent species found at Bass Lake as a food source. Neither of the submerged exotics in Bass Lake offers the same habitat structure as many native submerged species. For example, fish prefer the open structure found in native large-leaf pondweed (*Potamogeton amplifolius*) beds to the dense stands of Eurasian water milfoil. In addition, compared to natives such as large-leaf pondweed, Eurasian water milfoil leaflets serve as poor substrate for aquatic insect larva, the primary food source of many panfish.

The presence of curly leaf pondweed and Eurasian water milfoil is not uncommon this region. Although there is no data for Starke County, both species are present in nearly every public lake in the northern lakes region of Indiana (White, 1998a). Of the northern lakes receiving permission to treat aquatic plants in 1998, Eurasian water milfoil was listed as the primary target in those permits (White, 1998b). Purple loosestrife and reed canary grass are also common in northern Indiana.

Common reed is likely a newer addition to the Bass Lake plant community. In general, this species is spreading in an easterly and southerly direction from the northwest corner of the state. Its presence in Starke County is small, but growing. A large stand of common reed exists in an abandoned fish rearing pond at the former IDNR Bass Lake Fisheries Station. This stand is likely the seed source of the plants scattered along the lake's northern edge.

Summary and Macrophyte Management

Unlike many northern Indiana lakes that suffer from an overabundance of rooted plants, Bass Lake suffers from a lack of rooted plants. The lack of rooted plants may be contributing to the poor water clarity and may have long-term implications for the lake's fisheries community. To address these issues, the development of an aquatic plant management plan for Bass Lake is strongly recommended. The plan should focus on three primary goals: 1. the establishment of a diverse healthy rooted plant community through native species plantings; 2. a reduction in existing exotic plant populations and prevention of further introductions; and 3. the education of lake residents on the importance of a rooted plant community in a healthy, functioning lake ecosystem.

The establishment of a diverse healthy rooted plant community will likely require plantings. Plantings should occur only in areas where interference with other lake uses is minimal. For example, the resident survey revealed that few lake users utilize the northwestern corner of the western lobe. The low usage and relative physical protection afforded by the cove makes this an ideal location for the installation of native rooted plants. Individual residents who would like a more natural waterfront landscape might also consider planting native emergents. Artificial wave breaks/barriers may be needed to protect vegetation along particularly vulnerable portions of the shoreline.

Regardless of where plantings occur, only native species should be planted. Species can be selected based on the desired use of the area. For example, residents may want to plant submerged species such as large-leaf pondweed, Illinois pondweed, sago pondweed and eel grass to establish fish and wildlife habitat in the northwest corner of the southern lobe. According to Blatchley's work, this area originally supported many of these same species along with several others. Shoreline residents may prefer low profile emergents along their lakefronts so that their lake views are maintained. Typical low profile emergents native to northern Indiana include sedges, rushes, blue iris, sweet flag, pickerel weed, arrowhead, and arrow arum. Again, Blatchley's account of Bass Lake indicates many of these emergent species once thrived along the lake's shoreline. In general, residents can manage the plantings to suit their tastes and desired uses.

A variety of steps may be taken to reduce the existing exotic plant populations and prevent any further introductions. The current populations of curly leaf pondweed, and Eurasian water milfoil in and around the lake are fairly small and therefore would be most economically controlled by hand harvesting. Lake residents should learn to identify these species and remove them when they are encountered. Removed plants should be placed in solid waste containers for proper disposal rather than left in the water to decompose. While common reed populations are small, chemical treatment may be necessary given the difficulty involved in hand harvesting this species. Lake residents should also work with IDNR officials to control the common reed infestation at the abandoned IDNR Fisheries Station, which is likely serving as a seed source for the establishment of common reed populations along Bass Lake. Because their populations are larger, the control of purple loosestrife and reed canary grass may require periodic spot-applications of an appropriate herbicide, such as glycophosphate.

Residents should also consider posting an informational placard at the public boat launch to educate boaters on the spread of Eurasian water milfoil. The species is most commonly spread from one lake to another via vegetation fragments left on boat propellers. Requesting that users who may have recently boated in an infested lake clean boat propellers prior to launching the boat in Bass Lake will help prevent a re-infestation at Bass Lake. Properly cleaning boats will also prevent the spread of zebra mussels to Bass Lake.

PHOSPHORUS BUDGET

Of the two nutrients commonly examined during lake investigations, phosphorus is usually the one of most concern. Phosphorus is often the "limiting nutrient" in aquatic ecosystems, meaning that amount of phosphorus available to lake plants (including algae) limits the amount of aquatic plant growth. Based on the data collected during the 2001 sampling, it is likely that phosphorus is the limiting nutrient in Bass Lake. Plant tissue typically has a nitrogen to phosphorus ratio of approximately 7:1 by weight. The ratio of total nitrogen to total phosphorus in the surface water of Bass Lake is approximately 15.5:1. (Because algae growth occurs largely in surface waters where there is sufficient light, only surface nutrient concentrations are considered in determining the nutrient ratio.) This suggests that much more nitrogen is available to the algae compared to phosphorus. Reducing this excess of phosphorus may reduce the potential for algae blooms.

External Phosphorus Loading

J.F. New & Associates (New) developed a phosphorus budget for Bass Lake to assist in understanding the sources of phosphorus to the lake. The limited scope of this LARE study did not allow for field measurement of phosphorus inputs to the lake. New estimated external phosphorus inputs by using runoff coefficients for various land types. For the purposes of this phosphorus budget calculation, New utilized coefficients compiled in an EPA guidance manual by Reckhow et al. (1980). Reckhow et al. (1980) list a range of runoff coefficients for each land use. New used conservative estimates in the following calculation.

There are four sources of external phosphorus loading to Bass Lake: surface runoff over the watershed, direct precipitation to the lake, groundwater inputs, and phosphorus contained in the water pumped to the lake via the lake's deepwater pump. Table 22 presents the phosphorus inputs from various types of land use in the watershed. In total, the Bass Lake watershed exports approximately 238 kg (525 lbs) of phosphorus per year. New calculated phosphorus input to the lake via direct precipitation by multiplying the average yearly rainfall rate by an estimate of the typical concentration of phosphorus in rainwater and the surface of the lake. Because rainwater collection and analysis did not occur as part of this study, New utilized existing data to estimate the typical concentration of phosphorus in rainwater falling on Bass Lake. Two estimates were available for use: 0.019 mg/L, which is the value the EPA used in its National Eutrophication Study on Bass Lake (1975), and 0.03 mg/L, a value based on empirical data collected in Bloomington, Indiana (Bill Jones, personal communication). Using 0.019 mg/L as the typical concentration of phosphorus in rainwater, one obtains a direct precipitation input to Bass Lake of 75 kg/yr, while using 0.03 mg/L as the typical concentration of phosphorus in rainwater results in a direct precipitation input to the lake of 119 kg/yr. Given the amount of urbanization in

Bloomington's airshed compared to Bass Lake's airshed, the 0.03 mg/L likely overestimates the concentration of phosphorus in rainwater falling on Bass Lake. At the same time, the EPA value may underestimate the concentration of phosphorus in rainwater falling on Bass Lake. It is likely that the true value lies somewhere between the two, and consequently, the true value for the amount of phosphorus released to the lake via direct precipitation lies between the two given calculated above. For the purposes of this budget, this document will utilize the higher value for the back calculation of internal phosphorus load.

Table 22. Estimated external phosphorus loading from Bass Lake watershed land use.

Land Use	P-Export (kg/ha-yr)	Land Area (ha)	P-Export (kg/yr)	Percent of Total
Residential	0.5	185.3	93	39%
Row Crop	0.6	118.2	71	30%
Forest	0.2	314.6	63	26%
Pasture	0.3	30.1	9	4%
Shrubland	0.2	8.3	2	1%
Total			**238**	**100%**

Based on the hydrological model presented in the Hydrologic Conditions section, groundwater inputs account of approximately 46.8% of the total water budget, while water from pumping activities account for approximately 22.8 % of the lake's water budget. These water inputs are also sources of phosphorus to the lake since the groundwater contains phosphorus. Direct measurement of the concentration of phosphorus in the groundwater was beyond the scope of this project. On August 10, 2001, New collected a grab sample of water from the pump's outfall and had the sample tested for phosphorus. Total phosphorus in the pumped water was 0.18 mg/L. New utilized this value as an estimate of the concentration of phosphorus in the groundwater flowing into Bass Lake. (See Appendix H for details on the water quality of the sample collected from the pump's outfall.)

It is important to note that this 0.18 mg/L value is likely less than the true value of phosphorus in the groundwater flowing into Bass Lake. The groundwater flowing through Bass Lake is hydrologically connected to the surface water. Because Bass Lake's groundwater-shed is largely agricultural, it is likely that the near-surface groundwater is high in phosphorus. Additionally, there is no geophysical explanation for the high total phosphorus concentration from the pump's outfall, indicating that the phosphorus must be anthropogenic in nature (IDNR, unpublished memo dated July 1, 2002). These facts combined with the fact that the deeper groundwater reserves (pumped water) receive the benefit of filtering during percolation through the soil profile suggests the concentration of phosphorus in the *near-surface* groundwater is likely higher than 0.18 mg/L.

New calculated phosphorus loading from groundwater inputs (both near-surface groundwater flow and pumped groundwater) by multiplying the concentration of phosphorus in the pumped water by the amount of water flowing into the lake per year from the groundwater (2.16 x 10^8 ft^3/yr) and the pump (1.05 x10^8 ft^3/yr). The water budget modeling based on 50 years of hydrological data at Bass Lake determined the water inputs flows of 2.16 x 10^8 ft^3/yr and 1.05 x10^8 ft^3/yr. This operation yields a figure of 1,640 kg/yr. In other words, approximately 1,640 kg (745 lb) of phosphorus flows into Bass Lake from the groundwater and the pumped water combined. Table 23 summarizes the phosphorus load from each of the four sources.

Table 23. Estimated external phosphorus loading by source.

Source	Phosphorus Loading (kg/yr)	Percent of Total
Phosphorus from land use activities	238	11.9%
Phosphorus from direct precipitation	119	6.0%
Phosphorus from pumped water	536	26.9%
Phosphorus from groundwater	1102	55.2%
Total External Phosphorus Load	**1995**	**100%**

Internal Phosphorus Loading

Internal phosphorus loading is another source of phosphorus to the lake's water column. Bass Lake's bottom sediments release phosphorus under certain chemical and biological conditions. (The Water Quality section describes this in some detail.) Several sources contribute to the phosphorus in the lake's bottom sediments. These sources include dead algae, rooted plants, fish and other biota, sediments deposited from the watershed, and lawn waste or other organic materials that are directly deposited in the lake. Bass Lake bottom sediments may also still contain phosphorus from septic leachate. Lake residents have controlled phosphorus inputs from septic by installing a sanitary sewer around the lake. However, the lake's bottom sediments may still contain residual leachate phosphorus. These internal sources contribute significantly to the lake's total (external and internal) phosphorus loading rate.

New utilized Vollenweider's (1975) empirical model to estimate Bass Lake's internal phosphorus loading. Vollenweider's model states that the concentration of phosphorus in a lake ([P]) is directly related to the areal loading to the lake (L) and inversely related to the lake's average depth ($\bar{z}$) and flushing rate (ρ). The following equation (Equation 6) describes this relationship:

$$[P] = \frac{L}{10 + \bar{z}\rho} \qquad (6)$$

The areal loading (L) is the sum of the external areal loading rate and the internal areal loading rate (L_T=L_E-L_I). Dividing the total external load calculated above (1995 kg/yr) by the lake surface area yields the external areal loading rate. Once Equation 4 is solved for L, the total areal rate, the external areal loading rate can be subtracted from the total areal loading rate to determine the lake's internal loading rate (L_T-$L_{E=}L_I$)

The hydrological modeling indicates that Bass Lake's flushing rate, ρ, is approximately 214 days or 0.59 years (7 months). Bass Lake's average depth, $\bar{z}$, is approximately 1.8 m (6 ft). New calculated the lake's water column phosphorus concentration [P] by taking a volume-weighted average of the epilimnetic and hypolimnetic total phosphorus concentrations obtained during the 2001 sampling effort. Using approximately 15 feet (4.6 m) as the thermocline, the total phosphorus volume-weighted average concentration is 0.11 mg/L. Inserting these values into

Equation 4 and solving for L yields a total area loading rate of 1.44 grams of phosphorus per square meter of lake per year (1.44 g/m^2-yr).

To determine the internal areal loading rate, New subtracted the external areal loading rate of 0.35 g/m^2-yr from the total areal loading rate of 1.44 g/m^2-yr. This operation results in an internal areal loading rate of 1.09 g/m^2-yr. In other words, the internal loading of phosphorus accounts for 76% of the total phosphorus load; external sources account for only 26% of the total load.

Acceptable Phosphorus Loading

In his examination of lakes, Vollenweider found 0.03 mg/L to be the maximum acceptable concentration of phosphorus in a lake. Lakes that exceeded this concentration suffered from high productivity and low water quality. Using this concentration (0.03 mg/L) and Bass Lake's flushing rate and mean depth in Vollenweider's model, the acceptable areal loading rate for Bass Lake is 0.39 g/m^2-yr. (The line on Figure 56 divides the areal phosphorus loading rates into acceptable or unacceptable loading rates depending upon the lake's mean depth and flushing rate.) Multiplying 0.39 g/m^2-yr by the lake's area yields a total acceptable loading rate of 2220 kg/yr. Thus, in order to achieve a total phosphorus concentration of 0.03 mg/L in Bass Lake, total inputs of phosphorus would have to be reduced from nearly 8200 kg/yr to approximately 2220 kg/yr. This significant reduction in phosphorus control would be nearly impossible to achieve. Internal control of phosphorus loading will be needed to achieve such a goal.

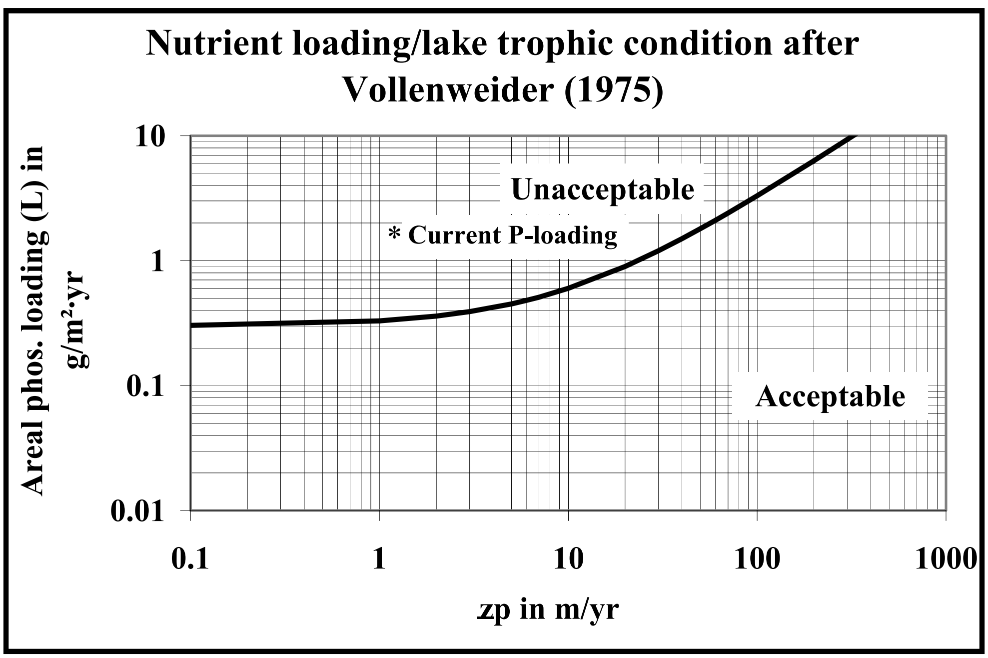

Figure 56. Phosphorus loading to Bass Lake compared to acceptable loadings determined from Vollenweider's model.

IN-LAKE MANAGEMENT

A variety of researchers (Scheffer, 1998; Cooke et al., 2001; Mott, unpublished) suggest that shallow lakes exist in one of two states: 1. clear and vegetated or 2. turbid and unvegetated.

Clear, vegetated lakes support a diverse fish community that includes top predators (piscivores) while a dominance of benthivores (bottom feeding fish) and planktivores (fish whose primary diet is zooplankton) and a lack of piscivores characterize turbid shallow lakes. The two lake forms often support differing bird communities as well. Piscivorous (fish eating) birds (e.g. herons) are more likely to wade along the shoreline of clear, vegetated lakes, whereas mallards and Canada geese are more common visitors to turbid lakes.

Both lake forms have positive feedback mechanisms that work to maintain whichever form the lake currently exhibits. For example, there is some evidence that vegetation controls turbidity through a variety of mechanisms (Scheffer, 1998). Vegetation helps stabilize bottom sediments from wind and wave action. It provides a refuge for zooplankton, the primary predator of phytoplankton. Some rooted plant species can secrete allelopathic compounds limiting algae growth. Similarly, rooted plants compete with algae for available nutrients and may affect the availability of nitrogen by creating conditions that facilitate denitrification. While none of these mechanisms may be sufficient to control turbidity, Scheffer (1998) suggests the combination of them can exert enough control to maintain a clear, vegetated lake. Conversely, turbidity, once it reaches a certain level, can impair the ability of rooted plants to grow, reinforcing the tendency for a turbid, unvegetated lake to remain unvegetated.

Fish communities also help maintain lakes in a given form. In clear, vegetated lakes that support a diverse fish community, piscivorous (fish eating) species assist in controlling planktivorous fish, whose primary diet is zooplankton. The zooplankton are then released from predation pressure enabling them to exert greater control over the phytoplankton (algae). Because phytoplankton contribute to a lake’s turbidity, control of the phytoplankton will assist in the control of turbidity levels. In turbid lakes, benthivorous species actively resuspend bottom sediments. Some benthivorous species, such as carp, are known to tear up rooted plant beds. The dominance of planktivorous fish in turbid, shallow lakes results in lower biomass of zooplankton and reduces zooplankton’s ability to control algae populations, adding to the turbidity problem. These and other feedback mechanisms make it difficult for a shallow, turbid lake to become clear and vegetated, and vice versa.

Despite the presence of these and other feedback mechanisms, shallow lakes can and do switch between the two essentially steady-state forms. The most common force causing the switch from one state to another is a change in nutrient concentrations, and the most common direction of the switch is from the clear, vegetated state to the turbid, unvegetated state. A simple example of how a change (in this case an increase) in nutrients can trigger the switch is described as follows: As nutrient levels increase in a naturally clear and vegetated lake, algae populations increase since they are feeding on the nutrients. The increase in algae populations increases turbidity. Once turbidity increases sufficiently, the lack of light retards plant growth. Plants die due to lack of light. The lake that was once clear and vegetated is now turbid and lacks vegetation.

Bass Lake’s place in the framework described above is clear; the lake is turbid and unvegetated. Fisheries data dating from 1972, recent Clean Lake Program studies, and current measures of water clarity indicate that Bass Lake possesses poor water clarity. Secchi disk measurements, which range from 1 to 4 feet, are lower than most Indiana lakes. Light transmission at three feet is low, usually less than 30% of the incident light reaching the 3-foot depths. Aside from the occasional outbreak of Eurasian water milfoil, records from the past three decades and the most recent plant survey show rooted plants cover less than one percent of the lake's surface area. Casual observations suggest that more planktivorous birds (Canada geese and mallards) visit Bass Lake than piscivorous birds (herons).

Bass Lake's fish community is the only component that does not fit the turbid, unvegetated lake model described above. Channel catfish, which are piscivores, dominate the lake's fish community. White crappie, white bass, and walleyes, all piscivores in at least one life stage, are important components of the community as well. IDNR fisheries surveys suggest that the lake's gizzard shad populations, an important planktivore, are decreasing. Additionally, the lake possesses low numbers of carp, a nuisance benthivore. Rather than being dominated by planktivores and benthivores, the lake appears to have an abundance or even over-abundance of piscivores and top predators. Stocking efforts (channel catfish in the 1940's and walleye in the 1980's to present) have undoubtedly played a role in manipulating the lake's fish community.

Although it is not definitive, the historical record suggests that Bass Lake may have once been a clear, well-vegetated lake. Blatchley (1900) describes the lake as "beautiful though shallow sheet of water" exhibiting a rich lake flora. Robertson (1973) contends that at a minimum "Bass Lake has been a much clearer lake [in the past] than it is at present." The historical records do not elucidate the causative factors that have resulted in Bass Lake's change from a clear, vegetated lake to a turbid, unvegetated lake. This diagnostic study revealed three existing conditions that have the potential to keep the lake in this state and prevent it from returning to the clear, vegetated condition. These conditions include 1. the watershed's current lack of tree cover/windbreaks coupled with the lake's natural morphology and long fetch, 2. the high nutrient concentrations in the lake, and 3. the heavy boating and personal watercraft activity on the lake. The following paragraphs explain how each of these conditions helps to maintain the existing conditions and explore lake management options to alleviate the impacts of these three factors.

Bass Lake's natural setting and morphometry makes the lake vulnerable to wind-induced wave action. The lake possesses a southwest to northeast orientation. Because summer winds are typically out of the southwest, the lake's fetch is quite long in the summer. Lakes with long fetches are susceptible to increased wave action. Given Bass Lake's shallowness, increased wave action results in increased turbidity as the wave energy easily extends to the lake bottom in many areas. Wave energy can also exert sufficient force to shear existing rooted plants and prevent the establishment of new plants. The lack of tree coverage around the lake, and particularly around the southwest portion of the lake, compounds the problem; no natural windbreaks exist to limit wind energy. These factors likely contribute, at least minimally, to the lake's turbidity problem and help keep the lake in its present turbid state.

There are few lake management tools available to change a lake's natural setting and morphometry. If the land were acquired, trees could be planted to create a larger forested buffer along the lake's southwest end. This would provide some protection from prevailing summer winds. Given the impracticality of this solution and the low probability for success, reforesting the southwest portion of the watershed is not recommended. The installation of wave breakers/barriers within the lake is another possible option to reducing wind-induced wave energy. However, these may interfere with desired recreational uses of the lake.

Fortunately, it is unlikely that the lake's natural setting is solely responsible for the lake's turbidity and lack of vegetation. Although more trees may have existed in the 1900's compared to today, wet and tall grass prairie habitats likely surrounded much of Bass Lake and covered its watershed. Prairie provides less shelter from wind energy compared to forests. Despite this probable lack of natural windbreaks, the lake maintained a clear, well-vegetated state. Thus, the bulk of the responsibility for the lake's current turbid, unvegetated state lies in the remaining two factors: the high nutrient levels and heavy boating and PWC use.

The high nutrient levels in Bass Lake probably play a bigger role in reducing the lake's clarity than natural forces operating on the lake. The historical and current water quality assessments of the lake indicate Bass Lake possesses high concentrations of total phosphorus and organic nitrogen. Total phosphorus levels exceed those measured in most Indiana lakes. In fact, by many accepted limnological standards, the total phosphorus concentration in Bass Lake indicates the lake is capable of hypereutrophic productivity (based on Carlson's TSI; Carlson, 1997). Additionally, total phosphorus concentrations appear to be increasing with time in Bass Lake.

The lake's high phosphorus concentration fuels algae growth. Algae density was extremely high in 2001 compared to previous years for which data is available. The phytoplankton data showed the lake was experiencing blooms of *Microcystis*, *Anabaena*, and *Lyngbya* at the time of the 2001 sampling. The exotic *Cylindrospermopsis* was also present at the time of the 2001 sampling. These genera belong to the blue-green algae group which thrive under high nutrient concentrations. This dense algal growth limits water clarity. Given that total phosphorus concentrations appear to be increasing over time, the lake could experience more frequent and severe algae blooms in the future, further reducing water clarity.

There are management options available to address high nutrient levels in a lake. Because phosphorus is the nutrient of most concern, it will be the focus of this management discussion. However, researchers (Scheffer, 1998; Mott, unpublished) have emphasized that high nitrogen levels are also of concern in shallow lakes. Therefore, lake residents should be aware that a reduction in nitrogen levels may ultimately be necessary to achieve the desired water clarity. Additionally this section will focus on the management of internal sources of phosphorus. The management of external sources of phosphorus to the lake will be discussed in the Watershed Management section of this document.

One of the most common and effective ways to treat internal phosphorus loading is through a strategy of phosphorus inactivation and precipitation (i.e., an alum treatment). Phosphorus precipitation and inactivation is designed to remove phosphorus from the water column <u>and</u> to prevent release of phosphorus from sediments. This nutrient control strategy is aimed at minimizing planktonic algal growth. The treatment involves adding aluminum salts to the lake. These salts form a floc or an agglomeration of small particles. This floc (e.g., $Al(OH)_3$) acts in two ways: (a) it absorbs phosphorus from the water column as it settles, and (b) it seals the bottom sediments if a thick enough layer has been deposited. Phosphorus can also precipitate out as an aluminum salt (e.g., $AlPO_4$).

Most phosphorus precipitation treatments employ liquid aluminum sulfate (alum) or sodium aluminate. The dosages are determined by a standard jar test, keeping in mind that aluminum solubility is lowest in the pH range 6.0 to 8.0. Cooke and Kennedy (1981) offer a detailed dose determination method. Aluminum toxicity does not appear to be a problem at treatment concentrations in well-buffered lakes as long as the pH remains above 6.0. Chemicals added for phosphorus control are applied either to the lake surface or to the hypolimnion, depending upon whether water column or sediment phosphorus control is most necessary.

The application procedure of aluminum salts to lake water has changed little since the first treatment in Horseshoe Lake, Wisconsin (Peterson et al. 1973). At Horseshoe Lake, alum slurry was pumped from a barge through a manifold pipe that trailed behind the vessel just below, and perpendicular to, the water surface. Today, new LORAN-guided high speed barges applying 4060 ft^3 (115 m^3) of liquid alum per day are the most advanced application vessels available (Cooke et al., 1993).

The season of application is critical for phosphorus removal, since different forms of phosphorus predominate in the water column on a seasonal basis. Phosphorus removal is most effective in early spring or late fall when most phosphorus is in an inorganic form that can be removed almost entirely by the floc.

Phosphorus precipitation and inactivation is most effective in lakes with long hydraulic residence times and low watershed phosphorus loading (Olem and Flock, 1990). In lakes with short residence times, new water from the watershed is continually replacing the water in a lake basin. If this water contains a high phosphorus load, the new phosphorus immediately replaces the phosphorus that was precipitated out of the water column. This new phosphorus also promotes the growth of algae and rooted plants. When these organisms die and sink to the lake's sediment, they form a new sediment layer over the alum treatment's seal. The seal is not able to prevent the release of phosphorus from the dead organisms that have settled onto the top of it.

Regardless of the lake hydraulic residence time, decomposition of aquatic organisms and sedimentation will naturally occur within a lake. This limits the alum treatment's effectiveness to approximately five to ten years (Olem and Flock, 1990). In some lakes, the phosphorus inactivation has been effective for as long as twelve years. The treatment's expected length of effectiveness should always be weighed against its cost. Costs vary depending upon the location and size of lake, type of applicator barge utilized for treatment, and other factors. Cooke et al. (1993) reports a cost of approximately $1,600 per acre ($640/ha) using a newer (faster) barge applicator.

An alum treatment should always be performed by an experienced applicator. An experienced applicator will test chemical conditions in the lake to ensure parameters are within ranges necessary to attempt a treatment (i.e. sufficient buffering capacity and water hardness). In addition, an experienced applicator will monitor the lake during treatment to ensure that the pH of the lake does not fall below 5.5-6.0. Below this pH range, conditions are appropriate for the formation of Al^{3+}, which is toxic to many organisms.

Cooke et al. (1993) outlines several of the potential drawbacks to alum treatments. These include the potential for increased rooted plant growth. As phosphorus that was once available for algae growth is removed from the water column, algae growth is reduced. This may increase water transparency. Increased water clarity allows for greater light penetration which could enhance rooted plant growth. Food chain impacts from the immediate reduction of algae could also affect a lake's fishery. Finally, the toxicity of aluminum even in neutral or basic conditions (pH >7) is of some concern to researchers.

While lake managers have conducted successful alum treatments on shallow lakes (Cooke et al., 2001), several aspects of Bass Lake may reduce the success or feasibility of an alum treatment. First, the heavy boating activity on the lake, coupled with the lake's natural shallowness, subject lake bottom sediments to significant wave energy. This wave energy could impair the alum's ability to form a seal over the lake's bottom sediments. Without the seal, much of the effectiveness of the alum treatment is lost. Additionally, the pattern of water column stratification/destratification, which occurs due to the lake's shallowness and heavy boating activity, could prematurely deteriorate the alum seal. Lastly, Bass Lake possesses a low alkalinity, suggesting the lake has limited acid buffering capacity. Without sufficient buffering capacity, an alum treatment may lower the lake's pH to an unacceptable level. Given these lake conditions, lake residents are advised to consult an experienced alum applicator to determine if an alum treatment is advisable on Bass Lake.

The third major factor responsible for lack of rooted plant growth and excessive turbidity in Bass Lake is the heavy boating and PWC use. Boats and PWC can directly destroy plant beds by shredding plants as the boats pass over the beds. Wave action caused by powerboats and PWC use can also damage rooted plants and prevent the establishment of new rooted plants. Boating and PWC use contribute to the turbidity problem in two ways. First, given the lake's shallowness, even boats using moderate horsepower levels transfer enough energy to the water to stir the lake bottom. Once the bottom sediments are resuspended, boating activities continue to keep the particles in suspension until the activities have ceased for a sufficient amount of time to allow the particles to settle to the lake bottom again. Heavy boating activity also adds to the lake's turbidity problem by facilitating phosphorus cycling from internal sources through the disruption of summertime stratification and via the transportation of phosphorus laden sediment to areas of locally high pH. (See the Water Quality section for a more detailed discussion of these mechanisms.) By facilitating phosphorus cycling, boating activities promote algae growth and, therefore, reduced clarity.

Managing powerboat and PWC use on the lake may be the most difficult work facing the lake residents. Many of options available to manage boating activity are likely to meet with some resistance given the popularity of boating on the lake. By increasing the lake's idle zone, lake residents have taken steps to alleviate the problems caused by boating, and they should be commended for this work. However, Bass Lake is a naturally shallow lake and as such is simply not capable of supporting the same level of powerboat and PWC use that other deeper lakes like Lake Maxinkuckee and Lake Tippecanoe are capable of supporting. Recent water quality assessments on the lake suggest that current levels of boating and PWC activities are causing ecological and aesthetic damage to the lake and that additional management is necessary.

There are several boating management options available to lake residents. These options include limiting the horsepower of the motor allowed on the lake, restricting power boating to certain times of day and areas of the lake, or prohibiting powerboating and PWC use altogether. The installation of wave barriers to help reduce wave energy may be possible. Lake residents would need to monitor lake use more carefully to determine the best placement of wave barriers. The drawbacks to wave barriers include: 1. they might interfere with some uses of the lake; 2. there is no quantitative measure of their effectiveness; 3. and given the number needed to protect Bass Lake, they may be cost prohibitive.

One possible compromise would be to restrict powerboat and PWC use to idle speeds only in the entire southwest basin. The entire southwest basin could thereby be protected from boating and PWC damager offering a permanent set-aside for native plant growth. Water clarity may improve as well. Morphometrically, the southwest basin is the best location for this effort. The southwest basin lies at the upwind end of the lake's fetch. Thus, wind induced waves are minimal compared to the northern end of the lake. Resident lake usage data also indicates that the southwest basin is the best place to attempt such restrictions. Over 20% of the survey respondents do not use the northern half of the southwest basin and another 20% do not use any portion of the southwest basin (Figure 7). In contrast, most respondents use the deep portions of the lake outside of the southwest basin.

To help encourage the use of idle speeds or passive boating in the southwest basin, the IDNR could move its public boat launch. Currently, the launch is located in the southwest corner of the lake. To travel from the public launch to the deeper portions of the lake, boaters must boat across a fairly lengthy no-wake zone. Casual observations suggest boaters routinely ignore the no-wake buoys, likely because the no-wake zone is so extensive. Moving the public launch to an area that provides quicker access to the deeper portions of the lake would help impatient boaters from bending the rules and thus impacting the lake's water quality. Of course, the IDNR must consider the safety, economic, and political implications of such a move, but based on the ecological implications, moving the public boat launch location should benefit lake health.

Ultimately, lake residents and other stakeholders (non-resident lake users, local and state government agencies) will have to decide how to best manage boating on the lake. Any management decisions should be made with a full understanding of how boating affects the lake. These management decisions must also take into account the fact that Bass Lake is a shallow lake and as such does not have the capacity to support the same level of boating and PWC use as deeper lakes do. As recommended in the Resident Survey section, lake residents and stakeholders should develop a use management plan for the lake.

WATERSHED MANAGEMENT

Unlike many other Indiana lakes that receive a fairly large portion of total water inputs from surface drainage, Bass Lake is primarily precipitation and groundwater fed. The water budget calculation estimates that nearly 70% of the lake's water input comes from groundwater sources (natural and pumped) and almost 30% comes from precipitation. Thus, in large part, the quality of the rainwater and groundwater determines the quality of the water in the lake. Unfortunately, lake residents have less control over the quality of these sources of water compared to the control they have over surface water quality. Despite this, lake residents can and should take special care in managing those aspects that are under their control. Two ways in which lake residents can directly influence their lake's water quality are: 1. by managing their own properties to minimize pollutant loads to the lake and to create natural habitat for the lake's fauna and 2. by treating the pumped water to reduce phosphorus loading. The following paragraphs described each of these in greater detail.

Residential Property Management

Proper lawn management can reduce pollutant loading to the lake. Many of the shoreline residences on the lakes have maintained turf grass lawns. Fertilizers and pesticides from these lawns are a source of nutrients and toxins to the lakes. Lakeshore landowners should reduce or eliminate the use of lawn fertilizers and pesticides. Landowners typically apply more fertilizer to lawns and landscaped areas than necessary to achieve the desired results. Plants can only utilize a given amount of nutrients. Nutrients not absorbed by the plants or soil will run into the lake, providing a nutrient base for plants and algae in the lake. At the very minimum, landowners should follow dosing recommendations on product labels. Where possible, natural landscapes should be maintained to eliminate the need for pesticides and fertilizers. Alternatively, landowners should consider replacing high maintenance turf grasses with grasses that have lower maintenance requirements such as some fescue (*Festuca*) species.

In addition to reducing the amount of fertilizer used, landowners should apply phosphorus-free fertilizers. Most fertilizers contain both nitrogen and phosphorus. However, the soil usually contains enough natural phosphorus to allow for plant growth. As a consequence, fertilizers with only nitrogen work as well as those with both nutrients. The excess phosphorus that cannot be absorbed by the grass or plants runs off into the lake. Landowners can have their soil tested to ensure that their property does indeed have sufficient phosphorus and no additional phosphorus needs to be added. The local Soil and Water Conservation District or the NRCS can usually provide information on soil testing.

There are several other ways for landowners to reduce pollutant loading to the lake. Landowners should refrain from depositing lawn waste such as leaves and grass clippings in the lake as this adds to the nutrient base in the lake. Any animal waste (from domestic or wildlife sources) along the shoreline will contribute nutrients and *E. coli* to the lake during runoff storm events. Pet and wildlife waste should be placed in residents' solid waste containers to be taken to the landfill rather than leaving the waste on the lawn to decompose.

To improve shoreline habitat and restore the functions of a natural shoreline, lake residents should consider replacing maintained lawns with native vegetation. In those areas that do not have seawalls, rushes (*Juncus* spp.), sedges (*Carex* spp.), pickerel weed (*Pontederia cordata*), arrowhead (*Sagittaria latifolia*), and blue-flag iris (*Iris viginica*) offer an aesthetically attractive, low profile community in wet areas. Behind existing seawalls, a variety of upland forbs and grasses that have lower same fertilizer/pesticide maintenance requirements than turf grass may be planted in place of the turf grass. Plantings can even occur in front of existing seawalls. Bulrushes (*Scirpus spp.*) and taller emergents are recommended for this. While not providing all the functions of a native shoreline, plantings in front of seawalls provide fish and invertebrate habitat. In addition, the restoration of native shoreline or the planting of emergents in front of seawalls also discourages Canada geese. The geese prefer maintained lawns as a food source and because any predators are clearly visible in lawn areas. Native vegetation is higher in profile than maintained lawns and has the potential to hide predators, increasing the perceived risk for the geese. Partial or full restoration of the native shoreline community with these measures would provide shoreline erosion control and filter runoff to the lakes, thus improving the lake's overall health without interfering with recreational uses of the lake.

Finally, local drains contribute sediment, nutrients, and thermal pollution to the lake. Each lake owner should investigate local drains, roads, parking areas, driveways, and rooftops. Paved surfaces should be kept clean and debris should be disposed of in solid waste containers. Where possible, alternatives to piping the water directly to the lake should be considered. Alternatives include French drains (gravel filled trenches), wetland filters, catch basins, and native plant overland swales.

Treatment of Pumped Water

It may be possible to treat the phosphorus in the groundwater that is currently pumped to the lake to supplement the lake water levels. Sample analysis revealed that the concentration of total phosphorus in the pumped groundwater is high; its concentration, 0.18 mg/L, is six times the generally accepted total phosphorus concentration required to minimize algae blooms. The phosphorus loading model indicates that this pumped water contributes nearly 27% of the external phosphorus load to the lake. While a reduction in this load would not solve the lake's phosphorus problem, it would be helpful.

Alum dosing stations have been constructed on inlet streams to treat phosphorus entering some lakes. By structurally modifying the pump's outfall, it may be possible to add an alum dosing component to one of Bass Lake's major "inlets". The dosing station would continually add alum to the pumped water in an attempt to inactivate the water's phosphorus. (See the In-Lake Management section for a full discussion of alum treatments.) A full feasibility study would likely be necessary to determine whether the addition of an alum dosing component is structurally possible and whether the benefits of such a system outweigh the costs.

RECOMMENDATIONS

Financial, time, manpower, and other restraints make it impossible to implement all of the recommended management techniques at once. Thus, it is necessary to prioritize the recommendations. Due to the overwhelming concern for the lake water level that residents expressed in the resident survey, recommendations to complete a more detailed monitoring study of the lake's groundwater system have the highest priority. The preliminary modeling completed in this study suggests the upper aquifer that provides the major input of water to the lake may be at least partially connected to the lower aquifer from which lake residents pump water to increase the lake's water level. If these two aquifers are connected, pumping water from the lower aquifer may negatively impact the upper aquifer, reducing the effectiveness of the pumping operation. Additional monitoring to determine whether the aquifers are connected, and if so to what degree, is recommended. This information will allow for a better determination of the optimal rate of water removal from the lower aquifer, if one exists. The monitoring will ultimately enable lake residents to make economically sound management decisions on supplementing lake water with deep groundwater.

While lake water levels may be of the most immediate concern to lake residents, residents are also urged to take action to improve the lake's relatively poor water quality. Inaction on this issue is ill-advised. The lake possesses high total phosphorus concentrations, and these concentrations have already resulted in nuisance, and potentially harmful, algae blooms. Many of the nuisance algae, including those that produce toxins, thrive in nutrient-laden water. The presence of nuisance algae such as *Cylindrospermopsis* has the potential to force natural resources and health officials to issue health advisories for the lake, limiting its recreational value. Additionally, the poor water clarity can reduce lakeshore property values. A study in Maine showed that poor water clarity can reduce property values by up to 20% (James et al., 1995). For these reasons, lake residents should strongly consider taking measures to improve water clarity.

As discussed in previous sections, lake residents cannot control several of the major sources of pollutants to the lake (i.e., pollutants in the precipitation and some of the groundwater). Of the pollutant sources under resident control, the management of boat and PWC use on the lake would likely provide the greatest amount of pollutant control for the associated cost. Boat use contributes to the lake's poor water quality by facilitating the internal cycling of phosphorus, resuspending sediments, and damaging aquatic plant beds. Bass Lake's shallow water depth naturally limits its capacity to support heavy boating and PWC use. Development of a recreational management plan for the lake should receive the next highest priority behind monitoring the lake's groundwater system.

With alum treatments, lake residents can exert additional control over internal phosphorus loading to the lake. Phosphorus modeling showed that internal sources contribute over 75% of the lake's total phosphorus load. Further control of this input is necessary to achieve a total lake phosphorus concentration of 0.03 mg/L. Because management of boat and PWC use on the lake may be necessary for an alum treatment to be successful, an alum treatment is recommended only after management of boating/PWC use is achieved. Given the characteristics of Bass Lake (its shallowness, low alkalinity), a full feasibility study is recommended to ensure the benefits of such a treatment are worth the cost.

This document discusses several other management options that are available to help lake residents improve water quality. These are included in the prioritized list below. While they may not provide as much benefit to the lake as boat/PWC use management or an alum treatment would, they should not be ignored. In fact many of the homeowner recommendations are relatively easy for individual homeowners to implement. By implementing these recommendations, homeowners will know they have contributed to the improvement of their lake's water quality and ultimately to their property's value.

Prioritized Recommendations

1. Implement the groundwater monitoring system recommended by Dr. Greg Olyphant to evaluate the existence and extent of connection between the upper and lower groundwater aquifers near Bass Lake.

2. Develop a recreational use management plan. The plan should be based on input from resident and non-resident users. All users should be provided information regarding the impacts

of boating, personal watercraft use, and other activities on the lake's water clarity and ecological health. This information will allow users to make informed decisions. Users should understand the existing limitations of the lake (its shallowness, lack of wind protection, susceptibility to algae blooms, etc.) before making use decisions.

3. Conduct a feasibility study to determine whether an alum treatment would be successful at Bass Lake, or at a minimum, consult an experienced alum applicator to obtain a preliminary opinion regarding the potential success of a treatment given the lake's characteristics.

4. Consider the feasibility of adjusting the pump outfall to allow for the addition of an alum dosing unit.

5. Develop an aquatic macrophyte (rooted plant) management plan. The plan should promote the establishment of a diverse, healthy rooted plant community through native species plantings. It should include action items geared toward the reduction of existing exotic plant populations and prevention of further introductions. The plan should also include an educational component stressing the importance of a rooted plant community in a healthy, functioning lake ecosystem.

6. Homeowner action items:

   a. Reduce the frequency and amount of fertilizer and herbicide/pesticide used for lawn care.
   b. Use only phosphorus-free fertilizer. (This means that the middle number on the fertilizer package listing the nutrient ratio, nitrogen:phosphorus:potassium is 0.)
   c. Consider re-landscaping lawn edges, particularly those along the lake, to include low profile prairie species that are capable of filtering runoff water better than turf grass.
   d. Consider replacing concrete seawalls with glacial stone.
   e. Consider planting native emergent vegetation along shorelines or in front of existing seawalls to provide fish and invertebrate habitat and dampen wave energy.
   f. Obey no-wake zones.
   g. Clean boat propellers after lake use and refrain from dumping bait buckets into the lake to prevent the spread of exotic species.

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